ENERGY SCIENCE AND TECHNOLOGY:

SUSTAINING

CANADIAN WEALTH AND JOBS

Submission to the:
Federal Science and Technology Review

Office of Energy Research and Development
Natural Resources Canada
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PREFACE

This report has been compiled by the federal Office of Energy Research and Development (OERD) as a submission to the Sustainable Wealth and Job Creation Task Group of the federal Science and Technology Review.

Its rapid production has been facilitated by the availability of source materials from the Energy Sector of Natural Resources Canada (NRCan), from the Program Review of NRCan, from Atomic Energy of Canada Ltd. (AECL) and from strategic plans for the interdepartmental Program of Energy Research and Development (PERD). We would like to thank these groups for making their information available to us in the preparation of this report.

Every effort has been made to verify the content and conclusions.

The complex nature of energy supply and use in Canada is reflected in the structure of this report which, following an overview, subdivides into seven energy industry groups. Five are commodity specific (Renewable Energy; Alternative Transportation Fuels; Oil Gas and Petroleum Products; Coal; and Nuclear) and two cross-cut the entire Canadian economy (Electricity; and Energy Efficiency). Profiles on the characteristics of each are provided with a focus on their present and future contributions to Canadian wealth and jobs. Each is accompanied by a science and technology strategy to ensure the sustainability of the particular industry, highlighting the federal government's role.

The complex nature and very different characteristics of these energy industries requires customised science and technology strategies and is not amenable to gross generalisation. However, a synopsis of key issues and conclusions is provided for each in order to facilitate rapid reading.

We would like to thank the many people across the federal government who provided information and commentary. In particular, we would like to recognize the lead role played by Gary Kugler of AECL in preparing the chapter on nuclear energy.

Energy is important to every Canadian, and it is therefore inevitable that many federal science and technology activities have an energy dimension. Despite the detail of this report, time and space limitations require that we generalise or make passing reference to some activities which could legitimately be elaborated further.

We regard this report as a valuable resource for planning for future federal science and technology investment in energy and recognize that it will continue to evolve. We therefore encourage contributions, criticisms and editorial suggestions which can be sent to:

Office of Energy Research and Development, Natural Resources of Canada
580 Booth Street, 14th Floor, Ottawa, Ontario K1A 0E4

Bryan Cook, Director General — Telephone: (613) 995-8860 Fax: (613) 995-6146

Kevin Cliffe, Director, Policy and Planning — Telephone: (613) 995-1525 Fax: (613) 995-6146

ENERGY SCIENCE & TECHNOLOGY:
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EXECUTIVE SUMMARY

KEY SECTOR DYNAMICS

Size of World Market

Energy and energy technologies are essential to both developed and developing nations.

World market is immense and growing. Canada's share of this international market could be large.

Strong North American trade linkages; Canadian energy commodity exports alone were $17.5 billion (1992).

Size of Canadian Market

The Energy Sector contributed $34.5 billion (1986 factor prices) to 1992 GDP; ie., 7.2% of GDP.

Structure

The energy sector is made up of a large number of companies diverse in size, maturity and organization. The oil & gas industry is comprised of clusters of MNEs and SMEs. Electricity is dominated by provincial utilities. Efficiency, ATFs and renewables are characterized by SMEs. Large Canadian-owned companies and utilities dominate the coal industry. All energy industries have associated clusters of engineering and services SMEs.

Employment

The energy sector accounts for 340,000 direct jobs. Indirect employment is substantial given the range of economic activities that support the energy sector.

Capital stocks

The energy producing sector accounted for about 17% of the $116 billion invested in Canada in 1992. This figure does not include investment by the energy efficiency, renewable energy or alternative fuels industries.

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Trade Balance

Canada had a **net** energy trade balance of $10.8 billion in 1992.

Industrial R&D Expenditures

The energy sector, including electrical utilities, invested $526 million in 1992 (latest data).

R&D Intensity

The R&D intensity of the sector has been declining in current dollar terms ($ R&D/unit of GDP) in recent years. Declines in the real purchasing power of R&D investment are even greater.

OTHER CONSIDERATIONS

Environmental Issues

The federal government has a role to play in the energy sector because of the government's commitments to environmental targets such as the reduction of greenhouse gases and ozone-depleting gases. Another role is public health and safety with respect to production and utilization of energy. These environmental issues and others such as urban smog, acid rain, water and soil contamination and solid waste disposal offer opportunities to develop unique Canadian expertise and technologies. Renewable energy and efficiency play a role in mitigating such impacts.

Future for Wealth Creation in Canada

Energy is the lifeblood of economic activities. Energy is required throughout the value-added chain, and a requirement in many high-technology applications. A reliable supply of energy at affordable costs is needed to maintain a healthy economy. Canada is fortunate in having vast oil, gas, coal, uranium and renewable resources; their development will create wealth, both domestically and through exports. Partnerships between industry and the federal government can and do:

i) improve the productivity of our energy and other resources;
ii) improve the efficiency with which we produce our resources, ensuring a reliable supply of reasonably priced energy;

iii) improve the efficiency with which our energy intensive industries use energy, thereby lowering their cost of production and enhancing the marketability of their products;
iv) enable Canadian manufacturers to establish secure positions in international markets.

Sharing high-risk and long-term R&D facilitates the development of a high technology manufacturing base in Canada and encourages the application of S&T to the design of energy-related regulatory policies, codes and standards which protect the environment and human health and safety without impeding industrial development.

ROLE OF S&T

Potential for S&T to Support Canadian Wealth Creation

Continued S&T is needed to:
- develop our large energy resource endowment in an environmentally responsible fashion;
- increase the productivity of our energy resource industry (oil sands, frontier oil and gas);
- improve the efficiency with which we produce and use our resources
- expand markets, domestically and internationally, for Canadian products and services;
- create jobs;
- develop world product and R&D mandates.

Characterization of the System of Innovation

Innovation in this sector is diverse and multidisciplinary, aiming at both processes and products. It includes advancement of technologies, cost\performance improvements, adaptation of processes or products to the Canadian environment, development of new uses and markets.

Product Life Cycle

Life cycles last from a few years to several decades. For example, transportation fuels change frequently in response to new specifications, whereas power production and pipeline infrastructure are long term capital investments.

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Ability to Innovate

The ability of the energy sector to innovate is ***high***; it has a good track record of innovation. The high level of collaboration through partnerships and consortia allows a rapid diffusion of innovative knowledge and technologies.

Strategic Innovation Needs

Efficiency:
combustion; heat management; end-use electrotechnologies; marketable products from wastes; commercial buildings; de-watering technologies.
Renewables:
lower cost, durable products, and system design.
Alternative transportation fuels (ATFs):
lower cost components, safety, enhance emission advantages, position industry for ULEVs and ZEVs.
Oil & gas:
economic and environmentally benign methods for the extraction and separation of bitumen from oil sands and its subsequent upgrading to high quality synthetic crude oil; Economic and environmentally benign methods to construct and operate exploration and production facilities, and oil and gas pipelines in permafrost regions.
Coal:
economic and environmentally benign methods for combusting coal and efficient conversion to electricity with high efficiencies.
Nuclear:
continuing CANDU support; new research reactor to replace NRU.
Electricity:
power system controls and power quality; better knowledge basis for environmental assessment.

Industry Capacity to Innovate

Industry's capacity to innovate is very high. It is highly dependent on the financial health of the particular industry and the economy.

Status of Production Technology

High technology and world class.

Sources of Technology

Domestic technologies are developed through industry and government partnerships for domestic market application and international opportunities. MNEs use expertise to develop product and research mandates based on Canadian needs. SMEs generally develop technologies and services in partnership with large companies and generally in response to a specific problem/issue. Other technologies are developed within government-sponsored research facilities (CANDU within AECL), or within government laboratories.

CURRENT PROFILE/IMPACTS

Federal S&T Sources

AECL	$153 million, of which $ 8 million is PERD
NRCan	$ 90 million, of which $ 50 million is PERD
F&O	$ 13 million, of which $ 6 million is PERD
TC	$ 6 million, of which $ 4 million is PERD
EC	$ 11 million, of which $ 7 million is PERD
7 Other Departments	$ 25 million, of which $ 11 million is PERD

Federal Support

Current federal suuport could be classified as follows:

Infrastructure	High
Research	Medium
Technology Development	Medium
Acquisition, Adaption, Diffusion	Low
Commercialization	Low
Marketing	Low

For the nuclear industry, the ranking would all be high.

Federal S&T Objectives

Federal energy S&T promotes the scientific understanding and technologies for Canada to produce, distribute and use its resources in a cost-effective and environmentally responsible fashion. Wealth creation, and sustainable energy development and use, complement energy security and health and safety as key policy objectives.

Federal energy S&T influences the S&T of our private sector partners to further invest in government priorities.

Over the long term, federal S&T has a role to play in high-risk research that neither the government nor the private sector can adequately support on its own. Industry also looks to government to use its broad-based expertise and specialized laboratories to develop a national base of knowledge.

Clients of Federal Programs

The main clients for federal energy S&T include:

- energy producing industries, utilities and industrial manufacturers;
- domestic and international cooperative R&D networks consisting of large firms, SMEs, environmental and engineering service companies, provincial governments and universities;
- environmental and health and safety regulatory and standards setting bodies, the federal government and the public.

Clients are extremely involved in R&D program design and promotion. Nuclear S&T is highly networked through the CANDU Operators Group and the equipment supply companies. Non-nuclear S&T is extensively networked through the interdepartmental Program of Energy R&D (PERD).

Impacts and Benefits (from federal S&T support)

<u>*PERD*</u>

- A recent analysis has shown that a sample of PERD supported projects levered a contribution from partners of over three dollars for every dollar of PERD funds invested.
- There is a high return from energy R&D investments in the form of new products, processes and services.
- PERD investments of some $32 million dollars generated net returns directly attributable to the Program of some $235 million to date. These benefits were mainly in the form of increased domestic and international sales, reduced energy consumption, and reduced O&M costs.
- Federal activities strongly support the "public good" component of S&T activities (greenhouse gas emissions, waste management and pollution; and public and

occupational health and safety).

<u>*Nuclear*</u>
- $6 billion worth of electricity and others goods and services annually.
- Direct employment of about 30,000.

Linkages/Spillovers

Federal S&T fosters linkages with companies involved in all aspects of energy production,distribution and use. For example, investments in efficiency are linked to all energy using sectors including buildings, processing, manufacturing, transportation, agri-food, and environmental industries. Investments in oil and gas are networked with exploration and drilling companies, environmental businesses, electronic instrumentation, pipeline and transportation companies, and with manufacturing industries (steel, valve and pump manufacturers) and other material producers (asphalt industry). Coal investment is linked to utilities, steel making, and rail transport sectors. Nuclear activity is closely tied to medical research companies, equipment suppliers, and high tech instrumentation to name but a few. Electricity is tied to utility and non-utility producers of electricity, electrotechnology manufacturers, consulting services, and a wide range of manufacturing industries. Linkages in renewable energy are strong with university research centres, niche market suppliers, and variety of SMEs, including: environmental industries, non-utility generators, manufacturers of pumps, electronic components and biomass furnaces/stoves. ATF activities are strongly linked to automobile equipment suppliers, fuel producers, and the vehicle manufacturers.

<u>OTHER CRITICAL FACTORS</u>

Canada's international obligations on the environment are common to many countries. The solutions are common, too, and this opens export opportunities. In meeting its own obligations, Canada's energy S&T can create wealth by supporting exports aimed at:

i) greenhouse gas reduction, through low greenhouse gas feedstocks such as natural gas as well as energy-intensive products such as aluminum, for which we could receive tradeable credits;
ii) greenhouse gas reduction, through goods and services for renewable energy and energy efficiency;
iii) stratospheric ozone protection, by CFC replacements and heat pumps; and
iv) ocean environment protection by export of goods, services and technologies for energy process wastewater cleanup and oil spill prevention and cleanup.

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Canada's international humanitarian obligations - and self-interest - can be assisted by export of energy technology to developing countries. Although the technology, goods and services must be appropriate and low-cost, it is nonetheless necessary to conduct S&T to achieve this.

FUTURE FEDERAL S&T OPPORTUNITIES AND STRATEGIES

Key Leverage Points for Wealth Generation

Energy Efficiency:
Development and deployment of energy efficient products and processes in all sectors.

Renewables:
Energy equipment (including small scale hydro-electricity) for job-intensive and environmentally acceptable growth of electricity generation.

ATFs:
Components of ATFs (including zero and low emission vehicles) for domestic and export markets.

Oil & Gas:
Economic and environmentally benign development of oil sands and frontier oil and gas.

Coal:
Economic and environmentally benign use of coal, including upgrading for exports.

Nuclear:
Continued support for CANDU engineering and radioactive waste management.

Electricity:
The provision of secure, reliable, high quality and affordable electricity.

Future Benefits and Spillovers

Past federal S&T continues to generate wealth. The recent impact assessment of PERD projects indicated that as much as $1.4 billion in benefits could be directly attributable to PERD. These benefits would be realized over the next five years from the small sample of projects analyzed.

Overall, federal S&T efforts will build on this track record, and will focus on realizing benefits through wealth generation (productivity, competitiveness improvements and jobs), environmental emissions reduction, energy diversification and the development of new domestic and international markets for Canadian products and services.

Some specific benefits include:

- wealth creation through development of Canadian resources and displacement of imported oil by domestic production;
- wealth creation through exports of oil and gas and associated technologies;
- contribution to sustainable development through greater degree of resource recovery (less left in ground);
- mitigation of environmental impacts of energy supply and use;
- continued supply of reliable, high quality and low-cost electricity through nuclear energy;
- reduction of CO_2, NO_x and SO_x emissions from electricity generation;
- expansion of SMEs' services and products in the energy efficiency, renewable energy and environmental service fields;
- wealth creation through utilization of Canadian coal for the production of affordable electricity and mitigation of environmental impacts;
- manufacture and export a wide variety of equipment for energy supply and use.

Federal Strategy:

A more strategic level of federal S&T support would be:

Research	Increase
Technology Development	Increase
Technology Acquisition	Increase
Commercial support	Increase
Infrastructure	Maintain
Export Promotion	Increase

Key Technology Areas:

Examples of key technology areas are:

Energy Efficiency:
Combustion, heat management, de-watering, electrotechnologies, commercial buildings, natural gas utilization, green agriculture, and marketable products for wastes.
Renewables:
Low-cost renewable energy components and systems, adaptation to cold climate, and biomass conversion.

ATFs:
Lower cost reliable components, emission reduction technologies, reducing risks to health and safety and build a basis for ULEV and ZEV components.
Oil & Gas:
Economic technologies for extraction, separation, and upgrading of bitumen and heavy oil (eg. surface science, process control technologies, catalysis, advanced separation processes, chemical reaction engineering, etc.). Economic technologies for operations in ice and permafrost. (eg. geotechnical engineering, materials sciences, remote sensing, etc.)
Coal:
Advanced combustion technologies; trace element extraction technologies; metallurgical coal beneficiation technologies.
Nuclear:
CANDU support and new research reaction
Electricity:
Power electronics, and electrical equipment.

Key Clients and Partners:

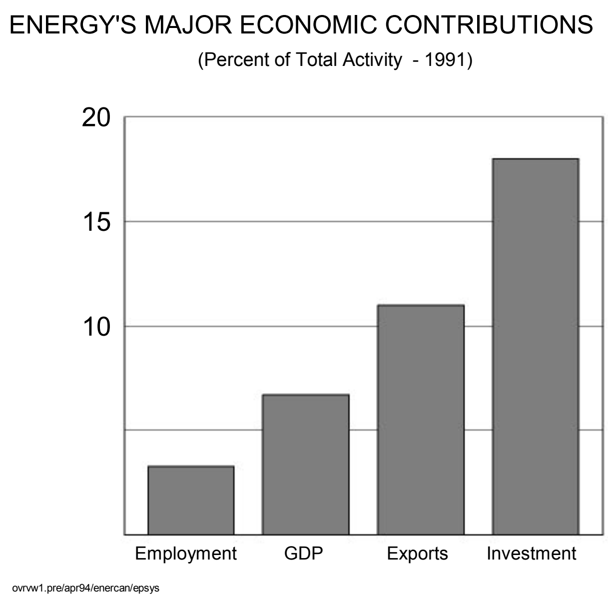
Energy Efficiency:
individual firms; consumers, farmers, fishermen; building trades; manufacturing industry; transport and agri-food industries; standardization bodies; other countries (through IEA collaborative R&D, Canada-USA MOU on Energy R&D).
Renewables:
solar and wind energy association; small manufacturing firms, forest products industries, utilities, CEA, municipalities and universities.
ATFs:
component SMEs, research departments of OEMs, hydrogen and electrochemical producers and users.
Oil & Gas:
MNEs, SMEs, engineering and consulting firms, universities, PRO's, regulatory agencies, provinces, foreign governments.
Coal:
large domestic companies, utilities, SMEs, engineering and consulting firms, universities, PRO's, regulatory agencies, provinces, foreign governments.
Nuclear:
nuclear power components manufacturers; engineering and consulting firms, uranium producers; utilities; and internationally (through IAEA).
Electricity:
CEA, utilities, government and manufacturing industry.

ENERGY SECTOR - S&T INTERFACE

Economic Importance of Energy

There is a fundamental strategic and policy importance of energy to the Canadian economy. The sector is a major contributor to GDP, employment, investment and trade. The production of energy is vital to regional wealth generation and employment. As well, the services that energy provides touch all aspects of economic activity in Canada in all sectors and in all regions. In total, Canadians spent about $45 billion on these services in 1993.
The importance of energy to the Canadian economy is reflected, most obviously, in the direct contribution that this sector makes to economic activity: the value of domestic energy production, in 1992 for example, was more than $34 billion (1986 dollars), or more than 7% of Canada's Gross Domestic Product. In terms of total employment, the production, processing and distribution components of the sector provided over 340,000 person years of employment. The sector also makes a significant contribution to investment (accounting for some 17% of the $116 billion invested in Canada for 1992) and exports ($17.5 billion) (see Figure 1).

Figure 1



The principal elements of the Canadian energy supply sector and the linkages between them are outlined in Figure 2 (1986 dollars). As indicated, an array of activities in each of the five major fuel categories (from exploration to distribution and marketing) contributes to meeting Canadian energy needs.

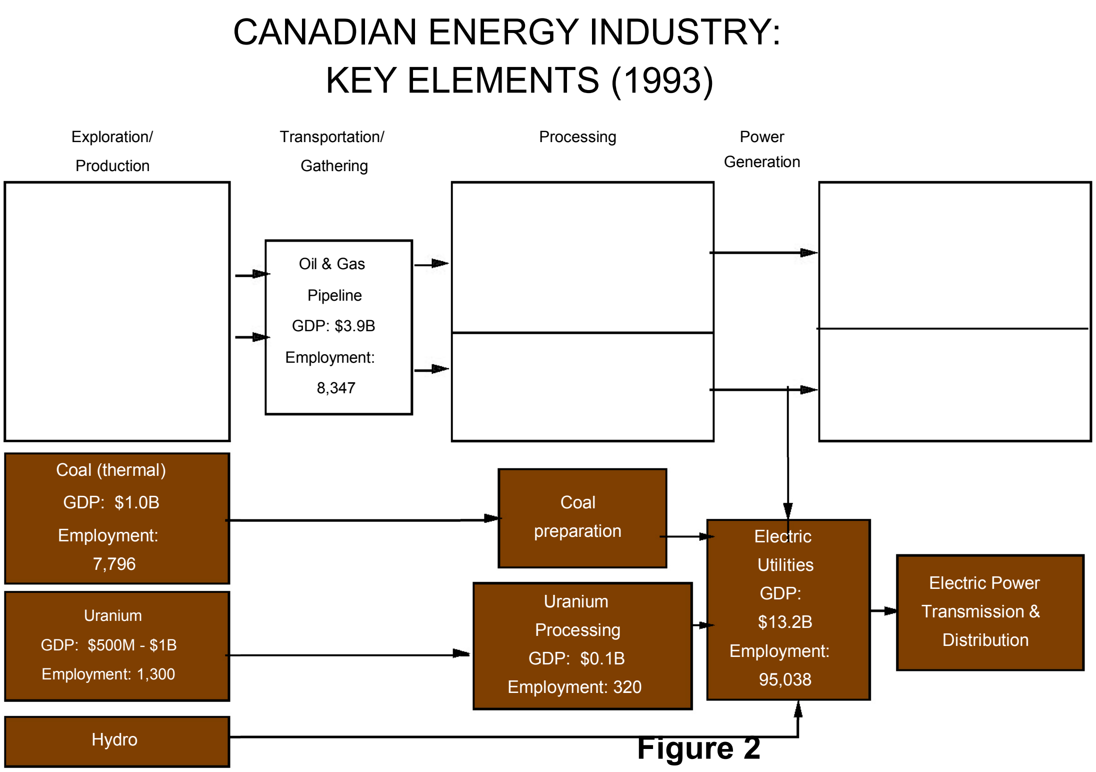


Figure 2

Figure 2 does not, however, provide a sense of the broad geographic context in which major energy flows take place. These include:

- crude oil produced in Canada's western sedimentary basin is transported by pipeline to refineries throughout the Prairies and in British Columbia, Ontario and the United States;

- uranium mined in Saskatchewan is transported to Ontario for refinement and then shipped to nuclear reactor sites in Ontario, New Brunswick, Québec and several other countries throughout the world;

- natural gas produced in Alberta and British Columbia is shipped by pipeline as far east as Québec City and as far south as California; and

- coal mined in Alberta, British Columbia and Saskatchewan is delivered by rail to Ontario and by ship to Asia, Europe and South America.

Figure 2 captures most of the activities that make up the energy industry. There are, however, several exceptions.

First, there are elements of the nuclear industry (besides the electric utilities) that deal with the design, production and servicing of reactors, and with nuclear research and development. This segment of the energy industry plays a major role in maintaining an indigenous nuclear industry and in developing and promoting domestic and foreign market opportunities.

The second involves the energy-related equipment and service sector. This sector includes the manufacturing and servicing of electrical equipment, and oil and gas field equipment. These activities are not usually considered part of the supply side of the energy sector. They are, however, attracting increasing interest, in light of export-led opportunities for growth.

The third segment of the industry not represented in Figure 2 is that of alternative energy (e.g., biomass, solar, wind, etc.). Due to economics, the main area of activity is biomass used in the pulp and paper industry, and wood used for residential space heating in rural areas. Currently, alternative energy sources contribute 6% of Canada's total energy requirements. Nevertheless, there is considerable interest in alternative transportation fuels (e.g., propane, natural gas, methanol and ethanol). There is also interest in the further development of biomass, and in niche opportunities for other forms of alternative energy.

Finally, Figure 2 does not mention energy efficiency, which is an important activity on the demand side of the energy sector. Increasingly, energy consumers and utilities are looking to energy efficiency improvements for reducing costs and increasing competitiveness. In addition, energy efficiency plays an important role as an instrument for addressing environmental concerns.

Energy Demand: Status, Recent Trends and Outlook

Total *secondary* energy demand in Canada (ie., energy delivered to users) grew by a modest average annual rate of 1.7% over the 1971-91 period. In 1991, the residential

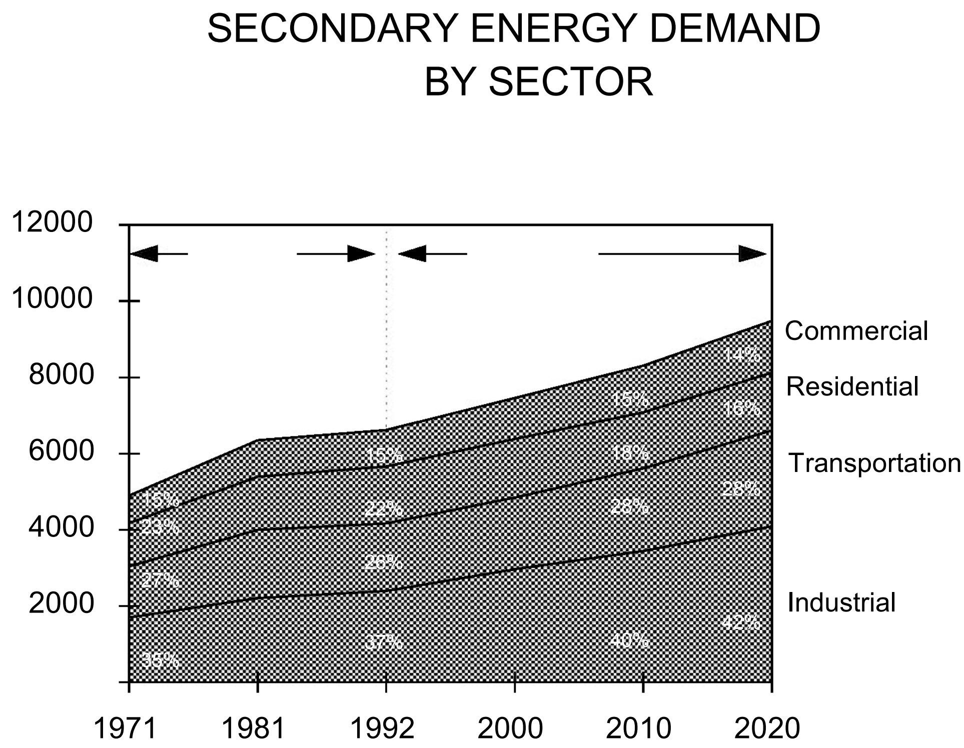
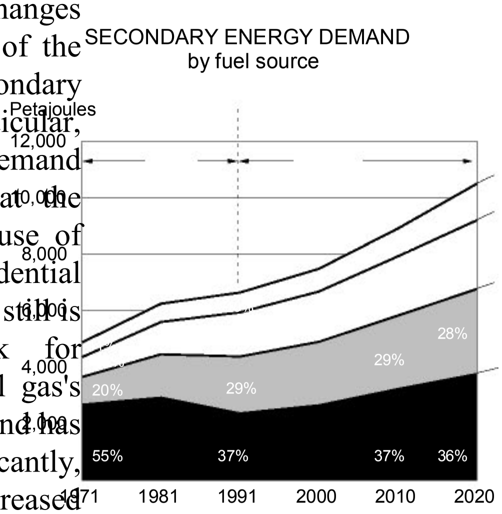


Figure 3

sector accounted for 22% of total demand and the commercial, industrial and transportation sectors accounted for 15%, 37% and 26% of total demand, respectively (see Figure 3).

As indicated in Figures 3 and 4, secondary energy demand is projected to increase to 7,500 PJ by the year 2000 and to 10,506 PJ by 2020. The implied average annual growth rate is 1.6%. Underlying this forecast is the expectation of relatively weak economic growth (2.5% per year), as well as some modest efficiency improvements in most sectors. The industrial sector's share of total secondary demand shows a significant increase over the forecast period, offset by a similar reduction in the residential sector.

Figure 4



Since 1971, some notable changes have occurred in the nature of the fuel mix underlying secondary energy demand. In particular, electricity's share of total demand has increased significantly at the expense of oil, largely because of off-oil substitution in the residential and commercial sectors. Oil still is the fundamental feedstock for transportation fuels. Natural gas's share of total secondary demand has also increased significantly, primarily because of increased demand from the industrial sector. It is worth noting that in 1991, roughly 75% of secondary demand was met with fossil fuels. The remainder of demand was met with hydro, nuclear and renewable sources (mainly biomass). Given the stable relative price forecasts used, Canada's secondary-demand fuel mix will likely remain unchanged for the forecast period.

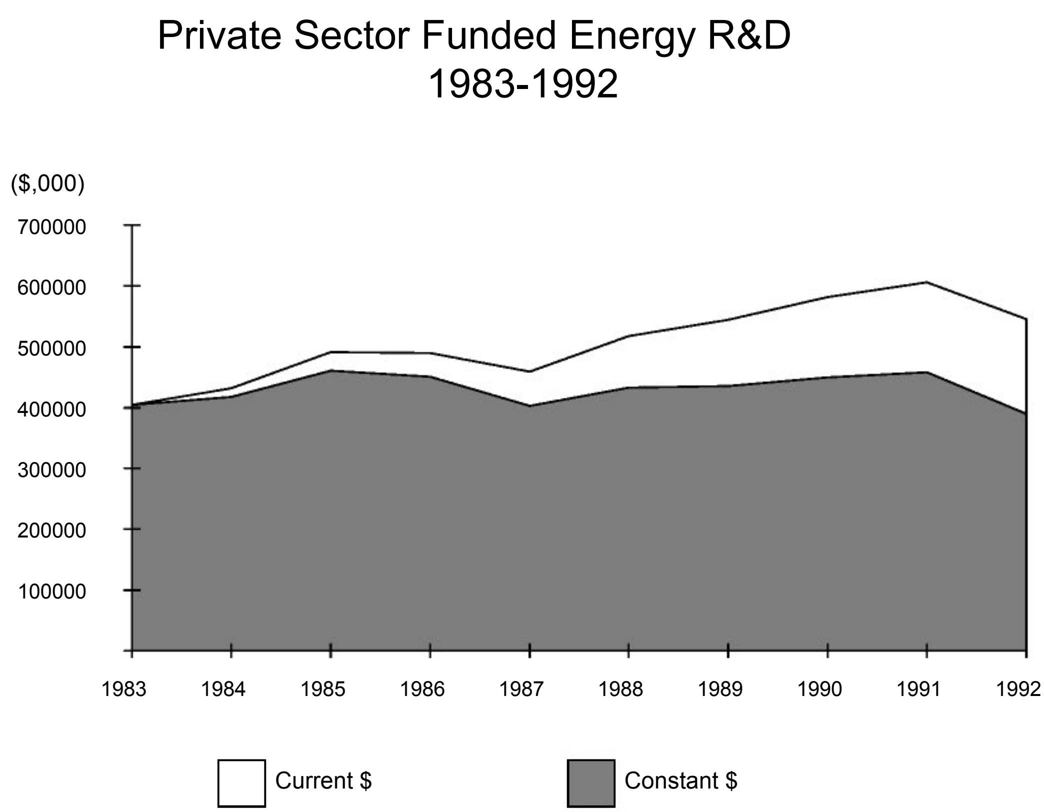
Energy Sector - S&T Interface

S&T Activities in the Energy Sector

a) <u>Industry and Utility Energy Research & Development</u>

In current dollars, the total energy R&D expenditure by industry and utilities was $526.2 million in 1992. This represents a decrease of over 13% from the previous year's figure of $608.1 million. Since 1983, total energy R&D expenditures for the private sector have increased at an annual rate of about 3%. However, the purchasing power of these S&T dollars has diminished over this period. In constant 1983 dollars, 1992 expenditures were $378.6 million, over 6% below the $404.7 million invested in 1983 (Figure 5).

Figure 5



Energy Sector - S&T Interface

b) Industry and Utility Energy Research & Development by Technology Area

Private sector investments on fossil fuel S&T have shown the greatest fluctuation over the years (Figure 6). In 1983, about 53% of private sector energy S&T was fossil fuel related. Since then, investment has fallen from a high in 1985 of about $260 million (53% share of private sector spending), to a low in 1987 of about $160 million (34% of private sector energy S&T investment). Investment has climbed slowly since 1987 despite the financial situation of the industry. In aggregate, 1992 energy S&T expenditures by the private sector on fossil fuels were about 18% below those of 1983.

Electric utility S&T spending has increased at an annual average rate of about 13% over the period, with most of this investment being in Transportation and Transmission. Private sector S&T spending in conservation has increased from $69 million to about $100 million between 1983 and 1992. Renewable energy S&T investments by the private sector have remained fairly stable for the same period.

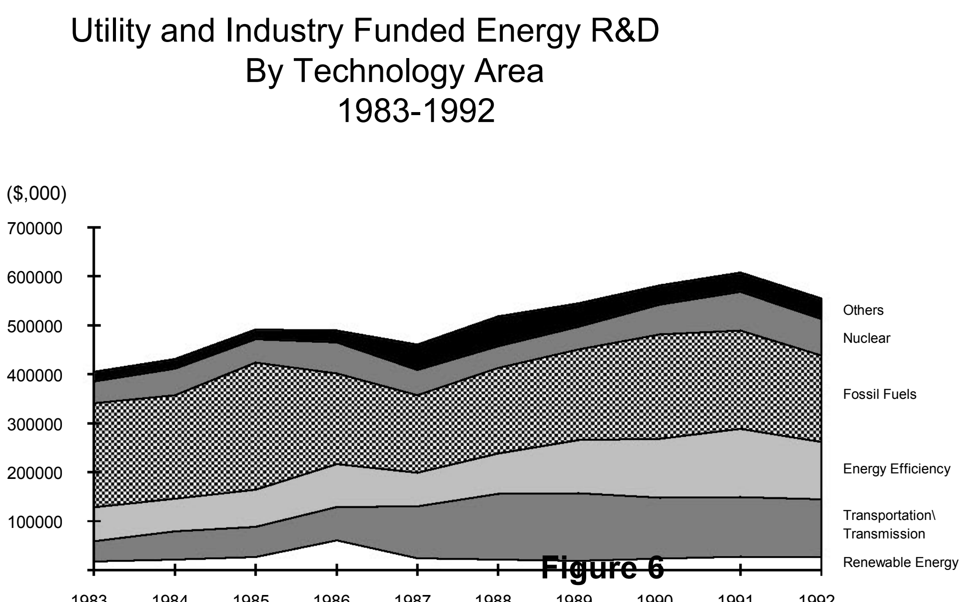


Figure 6

c) Federal and Provincial Energy S&T Expenditures by Technology Area

Figure 7 outlines the extent to which federal S&T investment has already been reduced in response to deficit reduction measures. Federal and provincial government energy S&T investments peaked in 1984 at approximately $587 million. Since then, federal and provincial investments have fallen to roughly $367 million in 1992 - a reduction of 37.5%. In constant 1983 dollars, 1992 aggregate federal and provincial energy S&T expenditures had fallen to $264.5 million, representing a decline of approximately 55% from 1983 levels.

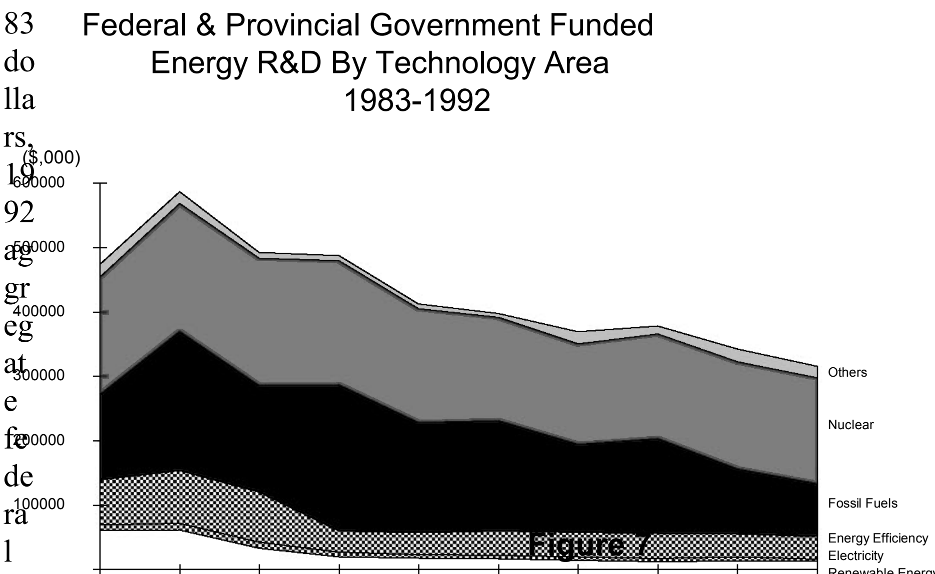


Figure 7

Fossil fuel (coal, oil and gas) and nuclear (fission and fusion) accounted for 66% of total federal and provincial energy S&T investment in 1983. Since then, their share has grown to 72%.

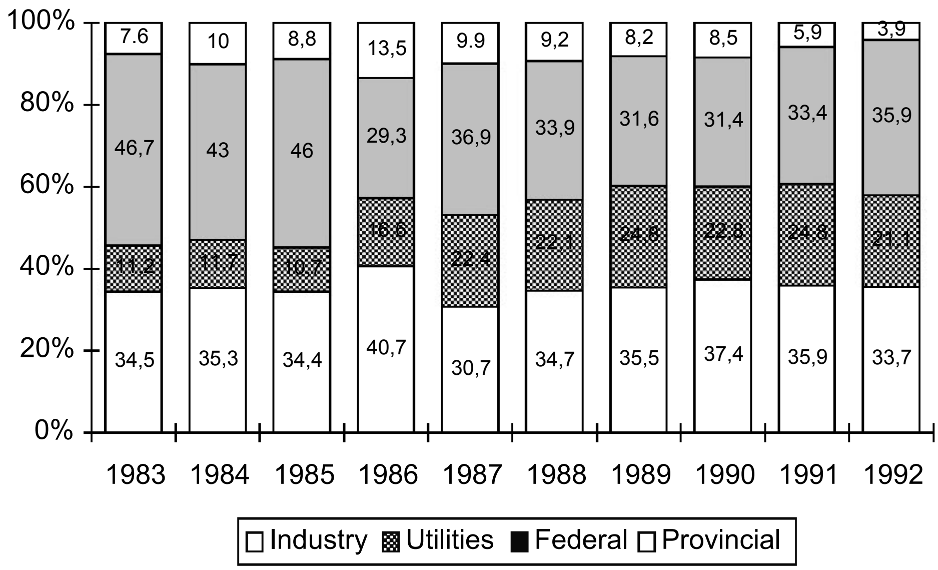
Energy efficiency investment has remained stable at 10% of annual federal and provincial expenditures throughout the 1983-1992 period. Investments on renewable energy technologies have declined from $61 million in 1983 (13% of total government expenditures) to approximately $13 million in 1992 (4% of total government investment).

Electricity related energy S&T investment (e.g., power conversion, transmission and distribution) by the federal and provincial government has dropped from $8.5 million in 1983 to $4 million in 1992. This represents about 1.7% of government total S&T expenditure.

Since 1983, a fundamental shift has occurred in the levels of S&T investment by industry, the electric utilities, and both levels of government. In 1983, the federal government invested about 47% of the total energy S&T expenditures within Canada. Since then, the federal portion has dropped to about 36%, roughly by 25%. Similarly, provincial energy S&T expenditures were reduced by approximately 50%. Industry's share of the investment

Figure 8

Canadian Energy R&D Investment
by Source of Funds 1983-1992



portfolio remained roughly constant at one-third. The largest area of energy S&T investment growth has occurred in the electrical utilities. The expenditure level in the sector has almost doubled to about 22% of total investment. This greater electrification of energy S&T has been mainly in the transmission and distribution areas. Utilities have expanded their networks to support growing market shares and to support their demand-side management activities. However, since 1992 there is evidence that utilities are re-examining and reducing their investments in S&T.

Federal Government Involvement in Energy S&T

Its economic importance makes energy a focus of government policy. The lack of substitutes and the inability of users to postpone consumption from one period to the next, highlight the need for reasonably priced and secure energy supplies. S&T is one of the government's policy tools that can help ensure that this need is met. S&T can reduce the cost of developing existing supplies, improves the efficiency with which energy is used, and diversifies our energy mix.

Energy projects have large capital requirements, and high levels of risk and uncertainty associated with them. S&T reduces these risks to ensure the timely development of these resources and the realization of their economic growth and job creation prospects. In addition, S&T also extends the productivity and economic life of existing resource developments, thus reducing energy supply costs, and deferring investment in new sources.

The distribution of Canada's energy supplies is done mainly by an extensive pipeline and electrical transmission network. Government S&T ensures that this infrastructure operates efficiently and is secure from major disruptions that could severely affect regional economic activity.

Appropriate application of existing technology or the development of new technology can help address the environmental concerns associated with energy production and use. In other cases, environmental considerations are addressed by improvements in energy efficiency and fuel standards. Incentives to pursue the appropriate preventive or mitigative response rarely exist in the marketplace. Governments have a responsibility to provide the regulatory and other instruments to address environmental concerns. S&T is essential to enhance the knowledge of the energy-environment interaction and develop the technologies to mitigate these impacts. S&T also helps to develop the technical basis for the design of the necessary codes, standards and regulations for good environmental stewardship.

Sustainable development issues will continue to influence energy policy and energy S&T priorities. Targetted energy S&T activities can address the issues of sustainable growth, and economic development. Energy S&T can promote the sustainable development of our resource industries and the economy through: the enhanced knowledge base necessary to understand the environmental implications of energy production and use; development of technologies to reduce emissions of air pollutants; and measures to reduce soil and water damage from energy producing industries, and nuclear waste managemnet issues.

Canada's international obligations on the environment are common to many countries. In meeting its own obligations, Canada's energy S&T can create wealth by supporting domestic application and exports aimed at:

i) greenhouse gas reduction, through low greenhouse gas feedstocks such as natural gas as well as energy-intensive products such as aluminum, for which we could receive tradeable credits;
ii) greenhouse gas reduction, through goods and services for renewable energy and energy efficiency;
iii) stratospheric ozone protection, by CFC replacements and heat pumps; and
iv) ocean environment protection by export of goods, services and technologies for energy process wastewater cleanup and oil spill prevention and cleanup.

Federal S&T can be classified by the nature of the work conducted, that is:

i) **Strategic S&T**
Generally medium and long-term projects with an element of risk, where the government takes a lead role, in association with industry partners, usually on a cost shared or task shared basis;

ii) **Incremental S&T**
Projects that extend and improve existing technologies, often of a short-term nature and performed for single or multiple clients on a cost-recovery or joint-work basis;

iii) **Exploratory Research**
New ideas and concepts for significant innovations, oriented to long-term industry needs as well as research relevant to government priorities; and

iv) **Certification and Testing Services**
Routine procedures performed by government laboratories to fulfil regulatory requirements or to serve industry with specialized capabilities.

Energy Sector - S&T Interface

Federal S&T can also be classified by the objective of the work performed; ie.,

i) **Productivity Activities**
To aid the competitiveness of Canadian industry;

ii) **Protection Activities**
To further the interests of health, safety, and environmental protection;

iii) **Policy Activities**
To investigate and advise on issues of concern to the government;

In the near term, federal government energy S&T influences the S&T of our private sector partners to further investment in overall government priorities. Most of the energy S&T conducted by the federal government is in partnership with the private sector. This enables the federal government to directly influence the level and direction of that S&T investment. Targeted S&T can contribute to expanded investment in such areas such as: the environment considerations for oil and gas development and abandoned site cleanup; development of new or enhanced markets for SMEs; or enhanced technical and marketing capabilities of Canadian renewable energy companies. In addition, geological research and resources assessment work enhance the knowledge of Canada's resource base, and are generally seen by industry as a role for government.

In the long term, federal S&T has a special role to play in high-risk research that neither the government nor the private sector can adequately support on its own. Federal support provides the risk-sharing and long-term stability needed for the efficient conduct of energy S&T, and for establishing the type of private sector partnerships fostered under the Technology Centres Policy. Industry also looks to government to conduct future-oriented research in such areas as new exploration techniques, environmental assessment and specialized laboratory services that can focus on national and cross-sectoral issues.

Energy S&T activities enhance the performance of Canada's economy. If we are to remain competitive, producers and consumers of energy must have the technology options for the production, upgrading and efficient use of all forms of energy supply. Technologies that improve the conversion efficiency of primary energy sources to electricity enhance Canada's electricity generation capacity. Similarly, the mix of short-term to long-term energy S&T activities in areas such as fusion, photovoltaics and cogeneration will augment electricity generation capacity. Also, S&T activities that focus on developing and enhancing conventional, frontier and heavy oil reserves will serve to both augment domestic petroleum reserves and reduce the threshold price at which such recovery techniques become economically viable.

Energy Sector - S&T Interface

Improved energy efficiency, diversity and flexibility of Canada's energy economy enhance Canada's energy security. Energy S&T to develop alternative and renewable energy sources equally contribute to this major policy goal. The development of alternative fuels and improved emission control systems contribute to a more diversified and flexible energy system, especially in the transportation sector.

If emissions regulations are to be developed for the sector, they must be developed from a sound technical and knowledge base. Continued energy S&T will enable a better understanding of the energy-environmental interaction, and the technologies that could address the implications of continued energy use. Energy S&T activities ensure that regulations can be developed for this, and other energy producing or using sectors, without imposing negative economic impacts on major industrial segments and firms.

Another major benefit of federal energy S&T has been the emergence of a number of environmental industries. Federal S&T has fostered partnerships between these companies and the resource industry to develop expertise and technologies to address key energy-related environmental issues. The strong S&T base has enabled these companies to expand their markets domestically and abroad.

Knowledge based S&T also makes a substantial contribution to industry activities and policy development. Resource assessments are used by oil and gas companies to plan exploration investment strategies, pipeline routes, and to make decisions on domestic versus foreign investment. Computer modelling of resource characterization and distribution contribute to optimization and competitiveness of resource industries, and provide a sound basis for the development of resource policies which minimize environmental impacts.

The Organization of Federal Energy S&T

There are two main arms of federal energy S&T: Atomic Energy of Canada Limited (AECL) which is responsible for the nuclear (CANDU) component of Canada's energy mix; and the federal interdepartmental Program of Energy Research and Development (PERD) which covers all other energy forms (including nuclear fusion) within Canada. Departments and agencies also carry out energy-related S&T activities on an individual basis, usually funded from their A-Base resources. Natural Resources Canada (CANMET, Geological Survey of Canada, Canadian Forest Service), Transport Canada, Environment Canada and Fisheries and Oceans are prime examples of this type of activity.

Energy Sector - S&T Interface

Energy Sector - S&T Interface

a) <u>Atomic Energy of Canada Limited</u> (AECL)

Atomic Energy of Canada Ltd.'s annual R&D budget of about $300 million is funded by: the federal government (50%); Canadian nuclear utilities (30%); and commercial work (20%).

The federal government provides funding to AECL Research Company both for R&D in support of the CANDU program and for broader, non-CANDU nuclear science and research activities. Net federal government support for nuclear energy has amounted to about $5 billion since 1952.

The nuclear utilities provide funding through the CANDU Owners' Group (COG). COG is comprised of AECL and the three Canadian utilities that own CANDUs (foreign CANDU owners are also members but do not contribute financially). Most of COG's funding comes from Ontario Hydro.

The funds provided by the utilities - about $90 million - are limited to use for R&D in support of existing CANDUs. Under cost-sharing arrangements with COG, these funds are matched by AECL using federal R&D funds. Therefore, only about 20% of AECL's total R&D budget - or about $60 million - is available for discretionary research.

AECL's non-CANDU research activities consist largely of basic science. AECL serves as a national laboratory for fundamental nuclear-related research in such areas as isotopes, nuclear medicine, basic physics, chemistry and material science, and environmental science. AECL maintains world-class laboratories and equipment, including an underground research laboratory for the study of nuclear waste disposal, and a sophisticated research reactor, the Tandem Accelerator Superconducting Cyclotron (TASCC). A small amount of funding is also devoted to R&D in support of advanced reactor concepts.

b) <u>Program of Energy Research and Development</u> (PERD)

The bulk of federal S&T related to the non-nuclear component of the energy sector is coordinated through the Federal Interdepartmental Program of Energy Research and Development. The objective of the Program is to ensure that Canada has the knowledge and the technology options to produce, distribute and use its energy resources in a cost-effective and environmentally responsible fashion.

PERD covers all aspects of energy production, distribution and use within the economy, including:

- energy efficiency related to standards, regulations, system design, health and safety, high-risk/longer-term technology development and technology development in the manufacturing, building, agrifood, transportation, and municipal sectors.

- clean coal focused on technologies contributing to the safe, efficient and environmentally acceptable exploitation, use and export of Canadian coals.

- nuclear fusion comprising the Centre canadien de fusion magnétique (CCFM), a magnetic confinement fusion experimental reactor, and Canadian Fusion Fuels Technology Project (CFFTP) advancing expertise in tritium technology established in the CANDU fission program.

- renewable energy focused on S&T to exploit Canada's renewable energy resources (hydraulics, small scale hydro, active and passive solar, photovoltaics, bioenergy and wind) and to investigate broad scale environmental issues associated with energy developments.

- alternative transportation fuels establishing the technical and regulatory base for a transition to potentially cleaner alternative transportation fuels in the next century, through the economical and environmentally acceptable use of coal, bitumen, heavy oils, natural gas, propane, biomass, alcohols (methanol, ethanol), electricity and hydrogen (including fuel cells). Canada is aware of energy activities in these areas and can promote Canadian S&T abroad.

- oil, gas and electricity to ensure that the government and industry have the technical knowledge to regulate and exploit the supplies of light-medium crude oil and natural gas found in Canada's frontier, through R&D addressing geoscience, engineering, environment, and transportation concerns. Electrical R&D to advance the science and technology related to the generation, transmission, and distribution of electricity.

The Program supports and complements the energy-related R&D activities of other federal departments[1]. An interdepartmental Panel on Energy R&D (the Panel) manages the Program, and is responsible for its strategic direction. PERD operates on an interdepartmental committee structure. Experts from participating departments and

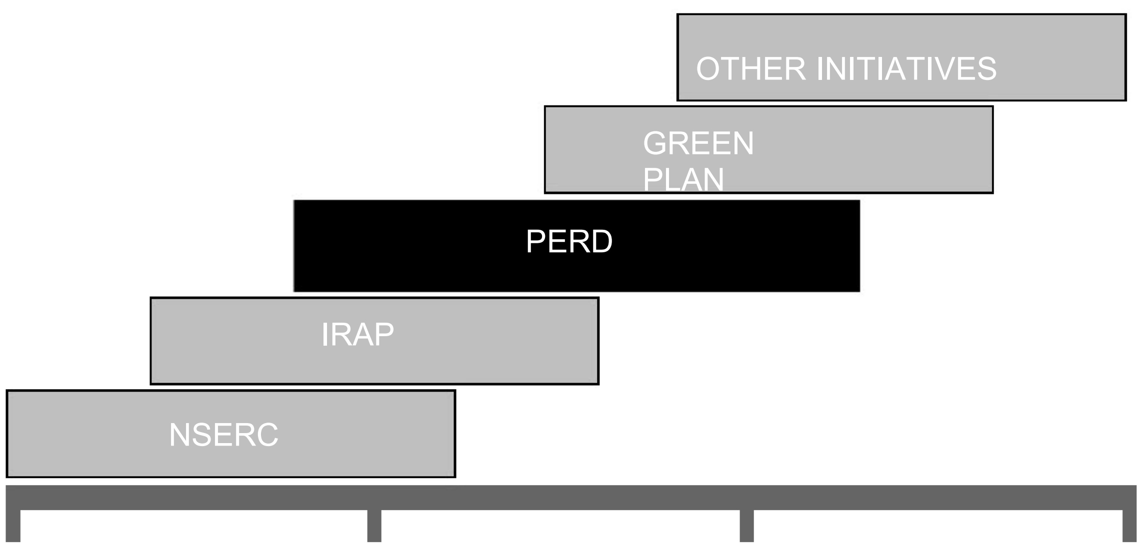
[1] The participating departments are: Natural Resources Canada (CANMET, Canadian Forestry Service, Geological Surveys of Canada, and National Energy Board), Agriculture and Agri-Foods, Environment Canada, Fisheries and Oceans, Transport Canada, Health Canada, Public Works and Government Services, Central Mortgage and Housing, Indian Affairs and Northern Development, National Defense, and the National Research Council.

agencies discuss and recommend a program of R&D to the Panel. This committee structure builds on the synergies between the key participants, and allows departments to pool their resources and activities to address common problems and issues. The committee structure has been proven to pool scarce resources, reduce duplication of effort, and to improve the decision making in federal energy R&D investment. The resulting program of R&D is approved by the Panel.

The interdeparmental nature of PERD provides a direct linkage between the activities of diverse federal departments on a variety of energy issues. This allows the participating departments to strategically plan and coordinate energy-related projects which are of joint interest. This process also allows for debate on the focus and balance of PERD's activities. Higher level debate on the Program's focus and balance is done, with the input of Ministers, on a cyclical basis in the form of a Cabinet submission which seeks Program re-confirmation.

Figure 9

PERD’s Relation with Other S&T Programs



Energy Sector - S&T Interface

Besides the committee structure, PERD also has a well developed and extensive network of federal, provincial, and industrial contacts. Frequently, industry, industrial associations, and provinces participate on PERD committees, or provide formal advice to the project selection process. These contacts ensure that PERD is well linked to their energy R&D activities. As well, participating departments have external committees that review their energy R&D programs (e.g., Minister's National Advisory Council to CANMET) to ensure their appropriateness and applicability.

A Memoranda of Understanding (MOUs) exist with the Canadian Electrical Association and strong linkages to industry associations (e.g., the Canadian Gas Association; the Canadian Petroleum Products Institute; the Canadian Association of Petroleum Producers; the Coal Association of Canada; and the Canadian Environmental Advisory Council) ensure that PERD activities are strongly complimentary to their activities.

At the international level, Canadian activities are coordinated with the International Energy Agency's program of collaborative energy R&D and with the USA through an MOU on R&D. These efforts ensure that Canadian energy R&D investment levers R&D investment by other countries. Often this collaborative approach to R&D results in opportunities for Canadian firms abroad, or the importation of technologies for domestic application.

PERD is also coordinated with the activities of other federal programs, including:

- NSERC, the Natural Science and Engineering Research Council's Strategic Grants Program which targets more fundamental research at universities in fields of national importance. The energy related component of the Program is about $2.8 million.

- IRAP, the Industrial Research Assistance Program (IRAP) of the National Research Council, which is a generic technical services program with major focus on technology base development, young scientist development, financial assistance for outside technical services, and collaborative project support.

- The Green Plan R&D, which demonstrates and commercializes environmentally related technologies, many of which have been developed with PERD funding.

PERD is the <u>only program</u> that focuses specifically on the energy sector, its contribution to the Canadian economy, and its consequences for the environment. As seen above (Figure 9), the Program's primary focus is applied R&D

While the other programs may have an energy dimension in the projects they support, energy R&D per se is left to PERD. Even so, the activities of these programs are coordinated. For example, NSERC strategic grants for energy are reviewed by experts within the PERD system to ensure coordination. In addition, Green Plan investments are discussed within the PERD Committee System.

PERD also helps develop regulations and standards that encourage rather than impede economic development. It has been instrumental in the development of material and structural codes for offshore oil development such as Hibernia, of vital economic importance to Atlantic Canada. PERD supported activities provide a technical basis for codes, standards, regulations to protect the public, workers and the environment. The Program also develops regionally based expertise in SMEs that understands the environmental processes effecting energy supply and use.

In 1984, PERD was severely reduced as part of the deficit reduction measures of the government. PERD funding was reduced from $164 million to $90 million. As a result of these reductions, funding in a number of areas has been reduced to the minimum level necessary to support a federal/provincial role. Further cutbacks would mean that investment in these areas could not be maintained, and that entire areas of program activity would have to be cancelled.

Energy Sector - S&T Interface

The 1991 Evaluation found the Program (covering the 1984-89 period) to be supportive of energy, economic development, and environmental policy directions. In addition, the evaluation found:

i) 79% of PERD supported R&D was performed outside government;

ii) 80% of the R&D was undertaken through joint partnerships;

iii) PERD caused some $220 million of additional energy R&D investment to be undertaken; and

iv) the Program influenced the direction of another $275 million of investment towards government priority areas.

Energy Sector - S&T Interface

PERD, and its main delivery arm CANMET, have established an on-going process of monitoring and evaluation. The purpose of this monitoring process is to determine the impact of PERD and CANMET investments in terms of their "public good impacts" (e.g., knowledge base development, environmental emissions reductions, and codes and standards) and "value for money impacts" (leverage, increased profits, reduced costs). The focus of the analysis is on the portion of these benefits that can be attributable to PERD and CANMET activities. Data obtained for these analyses are derived from annual project reports and completion reports of PERD supported projects, and surveys of CANMET clients. The data are verified by project managers who deal directly with industry contacts.

A recent study of these impacts has shown that PERD continues to be highly effective in generating economic spinoffs. A sample of 46 projects found that PERD investment of $32.1 million levered an R&D investment from clients of $100 million ($3.12 of client funds for every PERD $1). This investment generated $235 million of benefits directly related to the Program. Another $1.4 billion of anticipated benefits from these same projects could be attributable to PERD. Similar results have been achieved by CANMET.

Other Federal S&T Activities

Many federal research organizations undertake independent energy-related S&T activities. These agencies are members of PERD Committees, so there is good coordination between these A-Base activities and those of PERD. For example, the Geological Survey of Canada undertakes research programs on the disposition and extent of Canada's hydrocarbon resources. This basic data and research findings assist the resource industry in the successful and cost-effective exploration and production of these resources. These organizations have industrial advisory boards, business plans, and business targets to meet.
The Geological Survey of Canada (GSC), of NRCan, undertakes research programs on the disposition and extent of Canada's hydrocarbon (coal, oil, natural gas) resources. Approximately half of Canada is underlain by sedimentary bedrock. These rocks contain virtually 100% of Canada's fossil fuel resources - crude oil, oil sands and oil shales, natural gas, coal, and coal gas. Sustainable development of Canada's energy resources cannot even be attempted without first knowing both the character and the distribution of their host sedimentary strata. Basic geological data and research findings on the regional geological habitat of known and prospective fossil fuel deposits point the oil and gas industry toward success in exploration and toward conservation and efficiency in production. Products of the research are subsurface maps and cross sections, three-dimensional resource distribution models, technical research reports on known and previously undetected types of fossil fuel deposits and their geological environment, resource assessment reports, geological atlases, exploration concepts, and a wide variety of geophysical and

geochemical datasets. Such research, utilized mostly by small and intermediate Canadian companies, can lead to reduced finding costs, reduced production costs and increased overall efficiency in the energy industry.

Immediate and short term wealth creation flows directly from the release of many of the products of the GSC. Marked increases in Alberta land sales, for example, often follow immediately upon the publication of GSC reports or open files on the subsurface geology of specific strata or the general sedimentary geology of specific regions. Improved mine plans for surface coal excavations are commonly implemented by companies immediately upon receipt of the results of GSC's three-dimensional modelling studies (e.g. Estevan coal field, Saskatchewan). GSC's organic geochemichal capabilities are routinely called upon to solve immediate environment or even forensic problems - e.g. identifying the sources of spilled crude oil and establishing culpability.

Several of these research organizations already have in place performance measurement systems to measure their collaboration with industry, including cost-shared and task-shared work, revenues from intellectual property, licenses, and patents. The management systems in place enable impact analyses, similar to those mentioned above, to be carried out. The performance measurement systems and ongoing evaluations enable quantitative assessment of federal S&T impacts and successes. What remains to be done is to hasten the spread of these management systems to all government research organizations. On a higher level, the ultimate indicator of federal S&T impacts will be reflected in the increased economic activity and wealth generated, and Canada's environmental stewardship of its resources.

Structure of the Paper

The remaining segments of this paper provide a review of each of the sub-sectors that make up the complex and diverse energy industry within Canada. Each section provides a profile of the sub-sector, and its importance to the Canadian economy both now and in the future. In addition, each section reviews the role of S&T in the wealth and job creation efforts of the sub-grouping, its continued contribution to these efforts, and identifies the key areas where S&T can accelerate the realization of the sub-sector's wealth and job creation potential.

Energy Sector - S&T Interface

Synopsis: Energy Sector - S&T Interface

Importance for Wealth and Job Creation

- the energy sector is a major contributor to economic wealth and employment within Canada.

- Canadians spent about $45 billion on these services in 1993.

- the value of domestic energy production, in 1992 was more than $34 billion, or more than 6% of Canada's Gross Domestic Product.

- the energy production, processing and distribution components of the sector provide over 300,000 person years of employment.

Federal S&T

- Canada has a comparative advantage in energy which requires a substantial, and continued, S&T investment to ensure the cost-effective and environmentally responsible production, conversion and use of these resources.

- Canada's energy sector is a complex array of energy commodities, products and services.

- the industry is composed of a set of diverse firms in terms of size, maturity and industrial organization.

- the diversity of the sector leads to a variety of approaches to federal, provincial and industrial cooperation in policy and S&T.

- the bulk of fedral S&T is conducted in cooperation with the private sector. Government and industry work together, using the strenghts of each group to produce a better product than could have been produced by either operating alone.

- Atomic Energy of Canada limited and the Federal Program of Energy Research and Development are the two main players in federal energy S&T.

- nuclear S&T, the largest proportion of federal investment, is cost-shared with the provinces and utilities.

Energy Sector - S&T Interface

- non-nuclear S&T has organized itself to ensure that Minister's priorities are incorporated into the research efforts, and that there is an on-going process of monitoring and evaluation.

- other departments and agencies undertake non-nuclear energy-related S&T, with good coordination between PERD and non-PERD efforts.

- PERD provides a link between and strategic direction to the energy-related activities carried out within individual departments, as well as direct link to the activities and needs of industry.

- PERD, in recent years, has already undergone reduction for budget deficit purpose, about a 50% cut. In addition, departmental A-bases directed to energy related S&T have also ben eroded for the same reason. No inflation protection has further reduced all federal S&T energy funding.

Energy Efficiency Profile

Sector Overview

Introduction

Energy is a significant part (up to 30% in some cases) of the cost of goods and services in many economic sectors. It is also responsible for many pollutants. The efficient use of energy can significantly reduce these costs and the amount of pollutants produced. In addition, energy efficient technologies can often be developed and applied faster than new technologies in electricity generation or oil and gas production. Energy efficiency is also seen by many countries as a means to avoid costs of bringing new sources of energy on stream.

For these reasons energy efficiency has become a key element of wealth creation, and the cornerstone of efforts to address global warming, acid precipitation and urban air quality.

Canadians use about $45 billion worth of energy (6,722 PJ) each year - 37% in industry, 22% in homes, 13% in other buildings and 28% in transportation; and this is projected to grow at 1% per annum.

Each end-use sector presents a range of opportunities to use energy more efficiently without loss in productivity, convenience or comfort. Estimates of the amount that could be saved range from 20% to 50%. The variation stems largely from the degree to which the impacts of new technology are included.

Energy production and use account for 98% of manmade carbon dioxide, about 500 million tonnes per annum for Canada. It also accounts for most of the acid precipitation and a significant part of the urban air pollution. The easiest way to reduce the impacts and costs of energy use is to use it more efficiently. Improvements in energy efficiency are expected to account for as much as 75% of carbon dioxide emissions reductions in Canada's Greenhouse Gases (GHG) stabilization plan.

Energy efficiency can contribute to wealth generation in two ways: i) by reducing the cost of producing existing and new goods; and ii) by producing and exporting energy efficiency technologies, systems and services.

As the energy/environment links become more apparent and more widely understood, interest in energy efficiency will rise, thus, encouraging more activity by governments and industry. Better energy management will however only make incremental changes. Major impacts will require fundamental changes in products, processes and systems design. Such changes will not be driven by energy savings alone; major capital stock changes will be required. Technology development will thus remain key to achieving energy efficiency objectives, in the short and long terms.

Sectoral Profiles

Introduction

Energy efficiency is not a sector *per se*. Energy efficiency is a vector that cuts across all energy producing and using activities. The key dynamics, wealth generation opportunities and sustainability issues vary considerably across the end-use sectors of the economy. While there will also be in-depth sector profiles done by the appropriate departments, the profiles that follow will address sectors from an energy efficiency perspective only.

In this paper the energy end-use sectors of the economy are divided as follows: buildings, transportation, agriculture, fisheries, forest products, minerals and metals, food and beverages, chemical and petroleum refining, electrical and electronics.

Benefits in all sectors accrue from the application of technologies to reduce the energy costs of producing goods and providing services, and from manufacture and sales of technology. For example, it is estimated that the energy use in the industrial sector could be reduced by over 30% with the application of technologies now being, and to be, developed. Combustion, drying (water removal), power quality, recycling, advanced materials, systems integration, electric power drives and heat recovery technologies, when fully developed and if fully implemented, could save 20-25% of industrial energy use, amounting to about $2.5 billion per annum at today's energy prices. The following electricity related technologies, now being developed (fuse, motor controller, power factor controller, hydrogenerator and turbine, impulse drying and radio frequency drying) when fully implemented are projected to save about 22 PJ per annum and generate about $700 million in sales (nationally and internationally) per annum. The following non-electricity-related technologies now being developed (low NO_X gas burner, lubricating oil recovery, powder metallurgy, disc refiner, lubricating oil) when fully developed and implemented are projected to save about 45 PJ per annum and generate sales of about $378 million (nationally and internationally) per annum. [Note that these technologies would replace some existing technologies so that the numbers do not reflect net wealth generation].

Energy Efficiency Profile

Buildings

Key Dynamics

Building construction accounts for 11% of GDP in Canada ($75 billion). The construction industry is competitive but highly fragmented consisting of many small diverse companies. Officially, the industry consists of 150,000 companies of which 80% are small with annual gross revenues under $250,000. The majority are specialized sub-contractors or trades. The building sector employs 400,000 people directly and 1.3 million indirectly.

Canada has a net deficit in building products; exporting about $2 billion and importing about $5 billion. Building products are provided by a small number of Canadian firms and a large number of subsidiaries of multinational companies that either manufacture, assemble or distribute products for the Canadian market.

The residential and commercial building sectors account for about 33% of total Canadian secondary energy demand. The sectors spend $10 billion annually for space heating and cooling, water heating, ventilation and other appliances and office equipment.

Besides the direct energy consumption during operation, buildings imply massive indirect embodied energy. The production and transportation of cement, concrete, gypsum boards, insulation and other necessary materials all require energy. Furthermore, the maintenance of buildings (such as cleaning and repairs) also require energy.

New technologies, practices and systems being, and yet to be, developed could increase the energy efficiency of commercial buildings (retrofitted, reconstructed and new) by as much as 50% to 60%. In the residential sector, the Advanced Houses Program is demonstrating that new technologies can reduce energy consumption by 75% from conventional new houses, and more than 50% from R-2000 houses.

The building industry therefore has considerable potential to reduce costs to consumers and contribute to sustainability by reducing the demand for energy in renovated stock and new construction and from using construction and demolition wastes that would otherwise cost energy to dispose. Building operators can also create wealth by applying new technologies for energy systems integration, lighting and heat management to reduce energy demand. The components industry can create wealth by developing as much of the new energy efficient products as possible and marketing them domestically and abroad.

Energy Efficiency Profile

The sustainable development issues relate to energy use and thus carbon dioxide reduction, recycling and reuse of construction and demolition wastes, durability of buildings and the acceptability of indoor environmental quality by an increasingly health conscious population.

Role of Science and Technology

The buildings industry is very fragmented and diverse. As a result, it does very little R&D. The federal government has been the prime S&T investor, developing the basic knowledge of building physics and the performance of building structures, and encouraging and supporting the industry to modernize and become more innovative in construction and technologies. The federal government plays a catalytic role in bringing the diverse manufacturers and builders together. The federal R-2000 Program encouraged the residential construction industry to build not only better and more energy efficient houses, but also to develop the needed advanced equipment and products. The Advanced Houses Program has challenged the industry to be even more innovative. The C-2000 Program is expected to do for big buildings what the R-2000 and Advanced Houses are doing for homes. The NRC, in cooperation with NRCan and others, will issue Canada's first "Energy Code for Buildings" as part of the 1995 National Building Code. This represents the culmination of the national investment in energy related building S&T and will provide the framework for future technology application.

Since this industry is a major sector and an indigenous one, there is considerable potential for S&T advancement to create wealth in a wide diversity of areas including: R-2000 whole house export; advanced design tools; advanced domestic heating and hybrid appliances; ice slurry heat pumps; new building materials; advanced windows; new insulations; engineering of storage systems; waste combustion with heat recovery in building complexes and community energy systems, not only for domestic application to reduce energy costs, but also for export.

In the buildings sector, it is estimated that energy demand could be reduced by 50-75% by the application of new technologies now being and to be developed including high performance windows, innovative walls, high efficiency appliances, passive solar, retrofit of heating systems and integration of technologies in C-2000. High efficiency windows and high efficiency appliances (including heating systems) when fully developed alone could save over 200 PJ per annum which would cost about $2.7 billion per annum, at today's energy prices. In addition there is considerable potential in holistic approaches to healthy buildings, recycling of construction and demolition wastes, renovating and design for durability and smart houses/buildings.

The strategic need is to continue the integration of the sector started by R-2000 across the country and continue to push to develop innovative approaches to technology development and marketing. As well there is a need to develop holistic technologies for retrofitting buildings, manufacturing houses and applying high technology approaches which would provide healthy and economically sound investment opportunities. The level of skill in the industry urgently needs to be upgraded.

Transportation

Key Dynamics

The transportation industry in Canada is a major economic sector. It consists of the manufacturing of vehicles and components, and the transportation services system (operations, maintenance, infrastructure) in its various modes of road, rail, air and marine. Together they account for over $90 billion in shipments and over 600,000 jobs. The automotive industry is the main wealth generator. Total automotive manufacturing shipments were at an all time high of $56 billion in 1993, of which 80% was exported. Direct auto manufacturing employment, is 148,000 and total employment, including retail and after-market, is 500,000. The aeronautics sector employed about 43,400 people and achieved net sales of $6.7 billion in 1993. It is the sixth largest in the western world. The guided and urban transit sector together had annual shipments of $1.5 billion in 1993. Employment was over 10,000.

Moving people and goods is very energy intensive. The transportation services sector accounts for 27% of secondary energy demand in Canada. The vast majority of this demand (80%) is attributable to the road sector, followed by the aviation, marine and rail sectors. Practically all transportation is fuelled by oil-derived fuels, such as gasoline for passenger cars, diesel fuel for trucks, buses and trains, aviation fuels for aircrafts and heavy fuel oil for ships.

More than half of total freight is moved by trucks. Diesel power is used for transcontinental and some intercity. Urban freight is mostly gasoline powered. Rail is the main transcontinental freight mover and is in competition with trucks for much of this market.

The design of urban transportation systems and vehicle design (consisting of buses, trolleys, light low speed trains, intermediate high speed trains and subways) can have a substantial impact on the energy efficiency of moving people. This implies reduced costs, reduced pollution of urban centres and increased productivity.

Energy Efficiency Profile

The transportation manufacturing sector (truck/trailers, aerospace, auto parts, shipbuilding and motor vehicles) consumed 52 PJ in 1989 (or 0.7% of the net domestic use of energy in Canada). Energy is also used in the maintenance of vehicles, road construction and maintenance, management of traffic, roadway illumination and snow removal, road cleaning and de-icing.

High transportation energy costs can often reduce profitability and productivity in other sectors. For example, it is estimated that transportation costs are over 70% of the cost of building a house.

The transportation efficiency industry can generate wealth by: developing and applying new, less energy-intensive processes for making vehicle components; reducing waste in manufacturing; and reducing energy demand in maintenance of the transport system.

The sustainable development issues related to transportation are non-localized. The sector consumes an enormous amount of energy. It requires expensive road systems, causes urban air quality problems, produces considerable volumes of waste (tires, old vehicles and parts), and causes deterioration of buildings. Costly health related problems such as stress, accidents and diseases can also be attributed to the sector. Serious pollution, land use concerns and management of traffic problems have made personalized transportation an expensive social activity, yet it is still individually preferable as it provides freedom and independence.

Role of Science and Technology

In the auto industries, Canadian firms are basically suppliers of components and assemblers of vehicles. Therefore Canada has very little influence on the design of automobiles for energy efficiency.

The assembly sector is highly competitive and very successful. Contributing to this success are excellent product mandates, and a significant unit assembly cost advantage. The most important area related to energy efficiency has been the reduction of waste.

The components sector is very diverse. It is characterized by a small number of large firms and a large number of small and medium size firms. These firms have been very innovative in such areas as: powder metallurgy for auto parts, and wood waste for automobile door components, these innovations reduce the energy demand for making auto parts, thus reducing the overall cost.

Energy Efficiency Profile

Canada manufactures buses and trucks which use U.S.-made diesel engines and transmissions. These industries are innovative in vehicle design and add-ons, such as fairings to reduce drag, but these companies, especially the bus industry, are not presently very profitable. Innovative new technologies such as continuously variable transmissions, lighter weight structures and regenerative braking for city buses have the potential to increase energy efficiency and reduce costs. They could also be exported.

In rail, Canada has a nucleus of expertise in the use of turbines, LRC and 50 KV overhead electric traction, light low speed rail, intermediate high speed, subway systems. Most of the S&T on rail modernization is being done by CN and CP in their research facilities. Innovative ideas such as optimizing the use rolling stock, standardized freight cars, fuel quality, and reclamation of lubricating oils could have a substantial impact on reducing operating costs.

Canada's aeronautics industry is the sixth largest in the western world and competes very successfully in international markets. It includes small passenger-type commuter aircraft, aeroengines, parts, avionic and electrical systems, aircraft simulators and air traffic controllers. It is among Canada's highest R&D performers. Advanced wing design and new materials can contribute to the energy efficiency of Canada-manufactured aircraft. In the air transportation services, S&T can have an impact on energy efficiency in Canada in airport and flight operations .

Canadian S&T capability in ship building, ship operations and add-on equipment are in the Atlantic and Pacific provinces, with activities mainly carried out in universities and in government laboratories. Areas of work include: hull drag reduction; new hull designs; fuel management; propeller matching; and on board electronics. The ship building industry is, however, not in a profitable mode at present.

Science and technology can support the further development of wealth in two ways: i) by improving the efficiency of components production in new and innovative approaches to parts manufacturing to reduce the energy intensity and reduce waste materials and ii) by increasing the efficiency with which energy is used in transport services systems. This includes reformulation of fuels and lubricating oils for the Canadian climate, reducing demand of moving people and goods through the re-design of urban and intercity systems, re-design of airport and flight operations, integrated delivery systems, and applications of a range of modern electronic and communications systems. S&T can also reduce costs by utilizing wastes such as re-refining used lube oils, tires in cement kilns and recycling vehicle components.

In the longer term S&T can have considerable potential for wealth creation especially in such areas as fuel cells, hybrid drives, flywheels, rail electrification, hydrogen and batteries for electrified transport. These are areas in which Canada, with federal support, has developed considerable expertise. There is also great potential for reducing operating costs in the systems areas such as roadway lighting, urban traffic control, ground air traffic control systems, trucking systems and, in the longer term, intelligent vehicle highway systems (IVHS).

Thus, the strategic needs relevant to energy efficiency focus around systems optimization, add-on components, electrochemistry, electronic systems, manufacturing of advanced materials components and waste recycling and reduction.

Forest Products

Key Dynamics

The forest industry is responsible for more than $34 billion in industrial shipments and more than $20 billion in exports. More than 311,000 Canadians are directly employed in one of 4,200 forest product establishments located in all regions in Canada. Additionally, there are more than 466,000 people indirectly employed in activities that depend on the forest industry. More than 350 communities across Canadians depend on the forest industry for their economic prosperity.

The main characteristic of Canada's export market is a concentration in lumber, pulp and newsprint which are facing increasing competition in long-standing markets. Canada's global market has shown a declining trend in the past three decades. The industry has invested nearly $45 billion in new plant and machinery and in modernization and expansion to arrest this decline. This has resulted in an overall energy efficiency improvement of about 20%. Restructuring of the industry is taking place and will continue to take place to shut down non-competitive operations, increase product quality, promote added-value products and apply innovative new technologies. Many of these technologies will be energy efficiency related and could result in a further 20% increase in energy efficiency.

The sustainable development issues are related to wastes, chlorine bleaching and paper recycling. Over the past several years, over $5 billion have been spent by the industry on pollution abatement. More investment will be needed to address the other issues. These environmental expenditures are required over the next few years to meet the new standards imposed by governments and by public demand especially in relation to chlorine reduction in bleaching, closed-cycle plants, waste water clean-up and waste reduction.

Energy Efficiency Profile

Role of Science and Technology

Canada's three cooperative industrial forestry S&T agencies (FERIC, FORINTEK and PAPRICAN) conduct S&T, mostly of a generic nature. The federal government provides significant support for energy efficiency R&D through these agencies and through contracts and contributions to individual firms. Forest-based manufacturers and forest service companies carry out, or support, near term commercialization efforts using the results originating from the cooperative agencies. Provincial R&D programs focus mainly on applied R&D usually in concert with one of the three agencies and the federal government. In general, capital stock changes are very slow, but component technologies related to energy efficiency such as vapour recompression, high efficiency motors, heat recovery, water recycle, lumber drying, and electrotechnologies can be applied quickly.

Energy efficiency S&T advancement has significant potential to assist these industries to maintain their present markets, and develop new products in a wide range of areas. For example, radio frequency drying has the potential to considerably reduce the energy requirements of drying soft wood lumber, to dry lumber faster and cheaper, to kill off nematodes that Japan and Europe do not want in imported lumber and to produce a better quality of dry lumber.

The energy efficiency related strategic technology needs can be summarized as follows:

i) In the pulp and paper industry, energy efficiency related technology can make significant benefits in:

   - the fibre supply (access and recycling of waste paper with low energy intensive environmentally friendly technologies, de-inking);
   - the pulp preparation (refiners - ground wood is energy intensive, oxygen de-lignification);
   - black liquor (production of chemicals and energy with zero discharge in the environment)
   - the paper-making technologies (use of natural gas and electricity to remove water from the paper);
   - sensors and controls (to optimize and integrates processes); and
   - energy supply (new cogeneration technologies to offset the shift in energy mix - plants with innovative technologies require more electricity than steam).

ii) In the wood products industry, energy efficiency related technologies are needed in:

- kiln drying of lumber (electro-heating and natural gas utilization technologies);
- new construction products (composite walls, composite timber with minimum rejects and energy); and
- new products from previously classified "non-commercial" species of wood.

The majority of pulp and paper producers have world-scale operations located in remote communities situated close to the forest resource. There is a strong inter-dependency, between the lumber industry and the pulp and paper industry. Most of the by-products produced by lumber mills are used to produce pulp.

The major process technology manufacture is controlled by multinationals, some of which do research in Canada. Canadian firms have the expertise to develop a significant share of the equipment needed for energy efficiency but many of them are small. They need to affiliate themselves in consortia or clusters of firms to supply complete services in unique niche areas. They also require government assistance to develop and demonstrate technology.

Minerals and Metals

Key Dynamics

Canada's minerals and metals industry produces some 60 mineral commodities from some 280 mines. Canada has about 3,000 stone/sand/gravel operations and some 50 non-ferrous smelters. Minerals operations include mining, milling, smelting and refining, and metals-based semi-fabrication and fabrication. In total, these activities account for about 3.2% ($16.6 billion) of Canada's GDP. The industry is highly export oriented with up to 90% of the production of individual commodities being sold abroad. Exports of coal and total non-fuel mineral and mineral products generated revenues of about $24 billion in 1993. The non-fuel mineral and coal sector and metals-based fabrication employed some 335,000 workers in 1993. Mining related service industries provided a further 8,000 jobs.

Although the world-wide recession has produced a situation of excess supply and low prices, the long term outlook for world minerals markets is good. It will be stimulated by expanding population and economic growth especially in the developing economies. If investment can be raised from currently depressed levels, Canada's mineral production will likely continue to grow. Growth in domestic consumption is likely to remain moderate and mineral exports will continue to form a significant portion of output.

The minerals and metals industry is one of the largest industrial consumer of energy in Canada. The industry consumes about 22% of the total industrial use and 3% of the total domestic demand. Natural gas and electricity are the major sources of energy but petroleum and coal products still represent a large portion of energy usage. Energy cost can range from 5% to over 30% of production expenses, particularly at small remote sites. The industry will increase productivity by reducing its energy costs through the use of new technologies now being and to be developed especially in relation to environmental aspects which are energy intensive and in the making of added-value materials.

The sector is dominated by a few integrated companies but there are many associated clusters of small and medium sized companies specialized in consulting services and component equipment, particularly for the environmental solutions related to mining and processing operations. These SMEs can contribute to wealth by developing and marketing innovative technologies.

The most important sustainable development issues relate to mine wastes, mine site reclamation, waste utilization, waste water clean-up, metal recycling, advanced materials recycling and sulphur dioxide generation.

Role of Science and Technology

The federal government is a major S&T performer in Canada, with a portfolio of activities which includes mandated services, incremental R&D and strategic R&D. Provincial R&D programs focus mainly on applied R&D. The major technologies (e.g., cement making from a wet to a dry process) change slowly. However, changes in component technologies related to energy efficiency such as cement substitution with other materials; environmental technologies; process controls; heat recovery; and combustion of waste materials for energy in cement kilns can change quickly.

In terms of energy efficiency, the advancement of science and technology could reduce operating costs in diverse ways. One is to use waste materials to replace energy intensive materials for example fly ash, silica fume, and furnace slag to replace cement. Another is to use energy more efficiently from a systems point of view such as the better use of natural gas in steelmaking through preheating, pressurized combustion systems, process optimization, all continuous casting, coupling of continuous casting and hot strip rolling, coupling of pickling and cold rolling, scrap preheat, dilution of scrap with hot metal, and the application of expert systems to manage energy and emissions wisely. In the longer term, technologies such as direct coal injection to reduced coke in steel making, oxygen instead of air for combustion and fundamental new technology for comminution (in the much longer term) would significantly improve the energy efficiency and reduce emissions. The manufacture of a range of advanced materials (ceramics being largest component) to meet a wide variety of markets but especially for energy efficient automobiles and energy technologies is a major long term strategic need. Advanced materials, aside from creating more added value for our primary products, would have a significant part to play in energy efficiency permitting lighter weight vehicles, higher operating temperatures, reduced friction and wear, and better electrodes. Most of the innovation occurs in SMEs which show the highest growth rates. However, because they are small, they cannot afford to maintain significant R&D expertise and facilities. The federal government has therefore been the main centre of expertise in the country, developing and building a close-knit network of SMEs and rapidly transferring technologies.

The industry overall is facing and will continue to face stiff competition from foreign suppliers. Using technology to reduce energy costs (mining, production processes integration and optimization, recycling of waste, environmental technologies), could improve its competitivity and sustainability.

Agriculture

Key Dynamics

In 1992, the Canadian agri-food sector employed over 648,000 persons and generated total sales of over $67 billion. The agri-food sector is divided between primary production, at the farm level, and the food processing sub-sector which is covered separately in this document. At the farm level, there were 433,000 persons employed; and sales at the farm gate totalled over $23 billion.

Agriculture accounts for approximately 3% of Canadian energy consumption but energy expenditures account for over 10% of the total farm input costs. Gasoline, diesel fuels and other mobile fuels account for over 70% of the energy requirement.

Agriculture is expected to guarantee the Canadian food supply. Maintenance of the standard of living for farmers, operators of food processing facilities and ultimately, Canadian consumers, is dependant on the sustainability of this sector. As well,, they must maintain high quality standards and offset rising input costs by gaining acceptance in new markets, developing innovative technologies and improving overall efficiency.

The opportunities for wealth creation thus rests on improved productivity and reduced input costs which would open new opportunities for exports. Innovative technologies for energy efficiency in reduced fertilizer and pesticide use, reduced tillage, disposal of farm wastes, utilization of recycled human food for animals, dewatering, and integrated practices, which may at the same time increase productivity, can have a significant impact on input costs. Major equipment sales are dominated by multinationals but there is a role for Canadian SMEs in the development and marketing of energy efficient technologies.

Long-term productivity of the land-base is essential to ensure the long-term sustainability of the agriculture and agri-food industry. Agriculture is faced with a number of serious issues related to sustainability such as soil erosion, nutrient and pesticide pollution of water ways, liquid and solid wastes and, in the longer term, the possible impact of reducing biodiversity and climate change on present species. Energy efficiency can have a significant impact in addressing many of these issues.

Role of Science and Technology

Agriculture is a highly fragmented industry in Canada which, as a consequence, does very little R&D. Although agriculture is a provincial responsibility, the federal government has traditionally taken the lead to develop the knowledge base, and act as an integrator of S&T across the sector. Agriculture and Agri-Food Canada (AgCan) has been the leader in R&D for over 100 years. It operates 24 research establishments throughout the country, conducting strategic research, adaptive and problem-solving research and mandated services to the industry. Energy efficiency S&T is an element of the work done by AgCan. Primary production S&T is well integrated and organized through the Canadian Agricultural Research Council. Technology transfer is through the agricultural extension services of the provinces in cooperation with AgCan.

Farmers, in good times, are good innovators and take up new practices quickly. However these innovations have to be incremental. Farmers cannot afford to make radical new changes in practices or equipment rapidly.

Energy efficiency S&T advancement has considerable potential to increase productivity and reduce costs. Reduced tillage resulting in energy savings on mechanized operations, reduced soil erosion, precise placement of fertilizer and seed, nitrogen fixation and biofertilizers, dewatering and drying and integrated farming practices are some of the strategic technology needs which can reduce the demand for energy while achieving sustainable development goals.

Other strategic needs are development of the equipment manufacturing sector, and more agricultural engineers. Developing new equipment is usually a slow innovation process. This is particularly the case when proper use of the energy saving device requires new farming practices and/or extensive investment. Any new idea must be tested during several seasons to ensure that all considerations are made (e.g. how weed is controlled or spread, reduction of soil erosion, disease infections, mild/hard winters, and wear).

Most of the major equipment is made by multinationals. However there are many niches for Canadian manufacturers, and more attention should be paid to their development. Small equipment manufacturers often do not have any research people on staff.

The ability of the industry to capture the benefits of radical technological advancement is not good. The cost of radical change is too high. However, changes that do not carry risk of crop failure or high equipment costs can be quickly captured.

Food and Beverage Industries

Key Dynamics

The Canadian food and beverage industry has annual sales of $44 billion and employs approximately 215,000 persons. In 1990, the sector reported total energy costs in excess of $275 million, and about 12%.

The largest energy users are the breweries, with 1990 costs above $59 million, followed by distilleries at $38 millions, the groceries and food processors each at about $35 million, and the wineries at less than $1 million.

Companies in the food and beverage industry face serious challenges beyond those posed by the highly competitive global marketplace and environmental concerns. Consumers are more demanding than ever on product variety, quality and safety. This is compounded by the consumer's desire to spend less which places greater focus on product price comparisons. In addition, associations and firms in the food and beverage industry are faced with several free trade related problems (e.g., codes for frozen foods, packaging and labelling, and containerization) and environmental issues related to waste streams.

SMEs that have chosen niche markets are growing rapidly, and will continue to do well in a free trade environment. Larger firms are turning to these companies to produce niche market products for them. It is these firms which will generate future additional wealth.

Although energy is not a high percentage of input costs across the sector, there are many opportunities for reducing energy use and increasing productivity at low cost. These are basically related to heat management, cooling, refrigeration, dewatering, drying technologies (eg. alcohol drying), waste recycling and disposal, and new processing technologies (such as microwave and membrane separation). In addition new approaches to packaging and the trend towards dried food will have a significant impact on energy use in relation to transportation, storage and refrigeration.

Role of Science and Technology

In the food processing sector being seasonal, the accent is on fast processing. The industry does little R&D and is dependent on foreign innovation and equipment manufacturers. The beverage industry has been more innovative.

There is significant potential for energy efficiency S&T advancement to increase productivity in such generic areas as:

- refrigeration systems (use of waste heat, chilling systems, novel heat pumps);
- drying systems (natural gas dryers, thermal disinfecting of cereals);
- the use of membrane techniques (to minimize pasteurization processes);
- other water separation processes and expert control systems;
- packaging;
- dried food; and
- waste disposal and by-products for animal consumption.

The S&T expertise in the country resides for the most part in government laboratories and universities. There is a need to integrate this expertise with the SMEs to develop and manufacture and apply the above technologies. There is also a need for energy consultants and systems engineers who can sell services to the food and beverage processors.

Most of the large, leading firms are ready and eager to invest in new, more efficient technologies. However, even some large firms have a freeze on capital expenditures, and energy considerations are not a priority. Therefore, the benefits of energy efficiency technology advancement will only be captured in concert with improved productivity and better quality products.

Energy Efficiency Profile

Fisheries

Key Dynamics

Commercial fishing activity is concentrated in communities along the Atlantic and Pacific coasts as well as around the Great Lakes and Lake Winnipeg. In 1992, industry production was valued at $2.9 billion. Of this, Atlantic fisheries production was valued at $2 billion, the Pacific fisheries at $733 million and the remaining $160 million by the freshwater fisheries. Over 86% of the total production was exported.

On the Atlantic coast, the number of registered fishermen has jumped by 64% since 1974, from 36,500 to 60,000. Over the same period, federally licensed plants almost doubled from 550 in 1978 to 1,063 in 1991, and the number of plant workers increased by 46% (42,000 to 61,500).

The sector spends about $250 million per year on fuel and electricity. Energy cost as a percentage of the value of seafood products is therefore 9%, of which the majority (80%) is spent in fishing activities and the remainder in the processing.

Within the processing sector, larger plants represent approximately 10% of the population but over 50% of total fuel and electricity costs in 1992. Regardless of plant size, refrigeration, cold storage, waste disposal and recycling, water removal and drying, and ice-making constitute the most significant energy end use and present the opportunities for energy demand reduction.

Many of Canada's fish stocks are seriously depleted, some, like ground-fish, almost to the point of extinction (signs indicate that depletions are not just affecting the Atlantic fisheries). For others, salmon and herring for example, the price paid in the international marketplace has fallen substantially because of an over-supply of cheaper foreign product.
Some say the industry is not sufficiently market driven. It tries to find buyers for what it produces, rather than producing value added products that buyers want. Such products have the potential to create regional prosperity.

The industry is, in some sectors, over-capitalized in vessels, plant and equipment, and yet ironically, some of this capacity is in outmoded technology. Efficiency suffers as does competitiveness. More efficient, profitable and competitive commercial fishing operations, multi-purpose vessels, and integrated-function boat design employing the highest number of people without expanding harvesting capacity, is essential for sustainable fisheries development.

The sustainability issues are related to fish stocks. Although not related to energy efficiency, efficiency can play a part in maximizing fishermen's income from a smaller catch.

Role of Science and Technology

The fishing industry is largely composed of small enterprises that do no S&T. Energy efficiency has not really been a concern although energy is significant part of the cost of the catch. The federal or provincial governments also paid little attention to energy until the late 1980's and the S&T efforts were small, and mainly done through universities and naval architects with federal support. Despite this, these efforts have been very successful but overshadowed by the decline in fish stocks.

Creating a more fuel-efficient fishing fleet is important for the economy of many communities and for the sustainability of the resources. The fishing industry is one of the greatest users of fuel in the food industry. Energy represents 20% to 30% of operating costs. Improving hull designs and gear to reduce drag, developing and applying computer programs to optimize fuel use, making more efficient engines and propellers and finding where to fish more efficiently would help optimize energy use and profitability.

The strategic needs go beyond energy, but energy efficiency technologies have a significant part to play. They include:

- knowledge and technologies in the resource management (teledetection to count fish, control illegal fishing and reduce fuel consumption);
- harvesting techniques (selective gears, reduced drags, attraction systems);
- diversified fisheries (low energy aquaculture, deep sea fishing, other species);
- processing technologies (drying methods, cooking, thawing systems, and refrigeration systems);
- by-product processing (products other than fish meal, temporary storage of small volumes for processing in single locations); and
- multipurpose vessels.

Major restructuring efforts, fisheries management initiatives, and securing and expanding the resource base are significant steps which must be taken before the industry can again become a wealth generator. At present, it is therefore only in selected niches that the industry can capture the benefits of technology advancement.

Chemical Industries and Petroleum Refining

Key Dynamics

The chemical industry generates $11 billion in revenue. It is the third largest energy consumer, accounting for 15% of energy use). It has the fourth highest energy intensity per GDP of all Canada's manufacturing industries. It is composed of many companies of various sizes where energy costs can vary between $175,000 and $150 million. Two thirds of products from this industry are classified as petrochemical, a quarter as inorganic and the rest as organic and specialty products.

Canadian refineries have improved their processing equipment since the mid-1970's in order to increase their production of light products such as gasoline, diesel, and jet fuels. This rationalization should reduce costs and increase efficiency, thereby improving the competitiveness of the remaining plants. Projections indicate a gradual increase in demand for refined petroleum products over the coming decades. However, refineries will be faced with changing product specifications (such as reformulated gasolines) and environmental concerns, in addition to increased competition from larger-scale and more efficient refineries in the U.S.

Primary petrochemicals are divided into four groups: olefins (ethylene, propylene, butadiene, and butylene); aromatics (benzene, toluene and xylene); methanol; and ammonia. The primary petrochemical industry supports clusters of value-adding secondary industries such as agriculture, plastics, cosmetics, textiles, rubber, and forest products. Much of Canada's petrochemical production is exported to the U.S. and Asia. The diversity of the industry and its export-oriented nature means that its outlook is closely linked to world economic growth and its competitive position.

In the refining sector, there are twenty-four refineries in Canada operated by twelve companies. Two of the major refining centres are located in Edmonton and Sarnia. The current Canadian refining capacity is 284,000 m^3/d, down from 370,000 m^3/d in 1979. This reduction in capacity has been associated with the closure or down-sizing of fifteen refineries and the upgrading of two others.

The energy intensity of the chemical industries, as a whole, is strongly affected by the percentage of capacity utilized. In addition, low capacity utilization reduces profits and the investment rate in new energy efficiency equipment and in retrofit. Despite this, the industry has invested $3 billion in 1990 toward capacity expansion and modernization and has started to move from black to grey to white speciality products. The industry can maintain profitability by reducing its energy demand through the continued application of better control technologies; water removal; new electrodes; better heat management; process integration technologies; recovery of waste fuels; integrated industry clusters (by-product or waste from one industry as feedstocks for others) and, in the longer term, new process technologies. These major capital stocks tend to change only over long periods of time.

Role of Science and Technology

The chemical industries and petroleum refining are technologically sophisticated and important components of Canada's industrial manufacturing base. They are basically subsidiaries of multinationals. A considerable amount of research is carried out on process technology development world wide. There is a well developed network of engineering companies efficient at technology transfer. Equipment for the refining industry is also dominated by multinationals that also perform a considerable amount of research world wide and transfer technologies.

However, there has not been much technology development for improving energy efficiency of existing plants except for heat recovery; plant automation; insulation upgrading; steam consumption reduction; and furnace and boiler efficiencies within the sector.

New technologies related to energy efficiency can further improve the overall energy efficiency and productivity of these industries. They include:

- temperature assisted pressure swing absorption and membrane separation (to recover hydrogen in off gases);
- process heat optimization;
- advanced heat management and heat exchangers;
- advances in automated process control;
- expert systems; and
- natural gas technologies (pressurized combustion).

S&T advances in unit processes, especially in relation to process integration can also contribute significantly to energy efficiency. There is a limited capability of Canadian suppliers to develop process equipment. However, SMEs have a good potential to develop and supply component technologies related to energy efficiency in areas such as process controls; advanced motors; power quality conditioning; sensors and detectors; process integration; heat exchangers; heat pumps; combustion devices; and better use of waste fuels.

The strategic needs in this industry are the development and manufacture of the ancillary equipment and its marketing by SMEs and through world product mandates by multinationals.

The industry is highly capable of capturing the benefits of advancements in technologies. They have a long history of applying new technologies that have been developed by the major players in their sector.

Electrical and Electronic Equipment

Key Dynamics

The electrical and electronic equipment manufacturing industry ships about $17 billion in products annually.

It produces a wide range of products including industrial electrical equipment, electrical power generation equipment, electrical wire and cable, batteries, appliances, lighting, consumer electronics, microelectronics, computers and peripherals and telecommunications equipment. This product register will grow considerably as a result of electronic packages for the "home office", power electronics, and advanced motors and drives.

Manufacturers can be divided into two categories: small Canadian owned firms producing specialized products for niche markets and larger multinational, all foreign owned. The most successful exporting subsidiaries of foreign multinational have world product mandates.

The industry uses about 16 petajoules of energy per annum. Estimates are that about 15% -20% savings are possible using new technology now being or to be developed. In addition to the energy characteristics of the industry itself, the expanding use of electronic equipment could have serious negative impact on power quality. There is therefore a need for power quality control equipment.

The sustainable development issues are related to metals in waste water, solvents, waste materials (most of which can be recovered and reused) and to recycling obsolete electronic equipment.

Role of Science and Technology

The utilities of Ontario, Quebec and British Columbia have large well equipped laboratories with world class testing facilities and the industry works with them to develop products some of which are related to energy efficiency in manufacturing of products.

The manufacturing is dominated by foreign multinationals who have their own laboratories but their R&D is basically located outside Canada except in areas where their Canadian subsidiaries have developed world product mandates as a result of R&D cost-shared with the governments. Northern Telecom is the exception, being a Canadian multinational with major R&D facilities in Canada.

The industry does very little S&T related to energy efficiency. However there are many opportunities for energy efficiency S&T to improve productivity and reduce costs. They include waste materials recovery, waste solvents recovery, heat recovery, magnaforming and metals recovery from waste water.

The industry is likely to apply technologies that reduce waste along with energy and allows them to comply with environmental regulations but is unlikely to develop the technologies themselves. They have already applied many "housekeeping" type energy efficiency measures and have purchased new equipment which is more energy efficient.

The strategic needs would be the energy efficiency, electrotechnology and environmental industries taking an interest in providing goods and services to this sector, and the recycling of electronic equipment.

Energy Efficiency Profile

Assessment of Federal S&T Capabilities

Overview

The overall purpose of federal S&T in energy efficiency is to ensure that Canada has the continuing technological base (knowledge base, technologies, codes, standards, networks) needed to achieve short and long term energy efficiency strategic goals.

The federal work is meant to complement the work being done by industry. It is focussed in areas where industry is unable or unwilling to do R&D, but which are crucial to the development and maintenance of the energy efficiency technological base; and thus to the achievement of government goals of wealth creation, sustainability and carbon dioxide emissions reduction.

The role of the federal government in energy efficiency S&T is:

- to perform work of a "unique technical service" nature which lays the framework for identification of opportunities and for the introduction of technology in the market place. It consists of R&D and other studies needed for codes, standards, regulations, performance criteria, health impacts, environmental impacts; technical information for policy development; technology assessments and sector studies; technology intelligence; technology information packages; and energy audits.

- to reduce the risks associated with innovative technology development and introduction in the marketplace with the private sector. This consists of cost-sharing technology development and demonstration, usually on a firm by firm or consortium basis, for proprietary technologies in areas of strategic interest, and where there is resident expertise or expertise that can be fostered to develop and market the technology.

- to support, in cooperation with the private sector, universities and provinces, longer term/higher risk applied research (mainly in generic technology areas). This is in areas where the risk is high but public benefits are significant or where the knowledge will be of benefit to many sectors.

- to support fundamental research that leads to the extension of knowledge in universities and government laboratories.

- to develop and support the advisory and technology support infrastructure and information/intelligence systems and networks in cooperation with the private sector, universities and provincial governments, and internationally.

The government will cost-share up to 50% proprietary energy efficiency technology development in areas where innovative Canadian owned-SMEs with unique capabilities exist or where a Canadian subsidiary has unique expertise and can get a world product mandate. In both cases, there must be a real need for federal assistance, and real domestic and international opportunities.

In fragmented industries, such as fisheries, buildings and agriculture, the government is the key S&T performer. Its role is much broader than in other sectors and is crucial to the overall viability of these industries. It covers the full spectrum of S&T activities from basic research to technology development, demonstration, technology information packages, energy audits, etc.

The government also has an important role to play in developing the knowledge base for a broad range of generic energy efficiency technologies. In most of these, industry is unable (does not have or cannot afford to maintain expertise) or unwilling to invest in the R&D. Because of their short term focus on marketing today's technology, the knowledge base is not presently useful to them or is basically outside their immediate business interest.

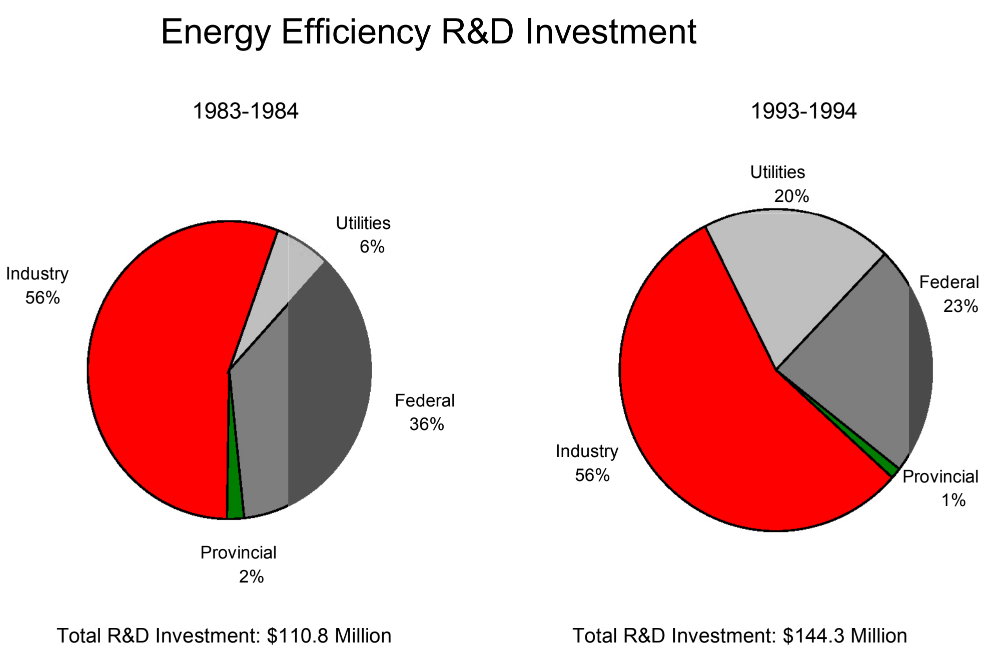
In addition, the government has a national coordinating role aimed at increasing interaction and collaboration among federal and provincial governments, universities and the private sector.

R&D Investment Trends

In 1983, a total of $110.8 million dollars was invested in R&D aimed at improved energy efficiency. Industry was the largest contributor providing $62.2 million. The next was the federal government which invested $39.5 million. The utilities provided less than 2% of the funds for a total of $7.1 million. The provinces' contribution was $1.9 million, less than 2% of total funds.

In 1993, the total R&D investment was $144.3 million. While overall investment increased, the federal government's investment declined by some 17% (i.e., from $39.5 million to $32.9 million). The decline in investment is in part explained by the significant reduction in federal support. In response to the deficit reduction needs of the Government, energy efficiency funding was halved in November 1984. Since then, the federal government has maintained its investment with some increase through the Green Plan.

Figure 10



The provincial governments invested slightly more in 1993 than they did in 1983, increasing their total from $1.9 million to $2 million. Industry increased its share of total contribution, now providing 56% of funds for a total of $80.4 million.

The electric utilities also increased their funding significantly to $28.9 million. Their investment in efficiency R&D was aimed at reducing their customer's energy needs and at increasing the efficiency of their generation operations.

Current Activities

The federal government funds and performs energy efficiency S&T through several programs in several departments. The major federal program for energy efficiency R&D is the federal Program of Energy Research and Development (PERD) which funds energy efficiency S&T in eleven departments and agencies (NRCan, AECL, AgCan, EC, F&O, TC, PWGSC, NRC, CMHC, ND and HC). The Green Plan in NRCan, departmental "A" bases, IRAP, NSERC, Environmental Technology Commercialization Program (ETCP), also support projects related to energy efficiency. Departmental "A" bases and the Green Plan in NRCan support the full spectrum of S&T activities.

Buildings energy efficiency S&T is performed by the departments which have mandates in the buildings area. R&D is through PERD, the Green Plan and "A" base. NRCan is the lead department with its Building Energy Technology Advancement (BETA) program that is working to develop a new generation of energy-efficient and passive solar technologies. If fully implemented, these technologies could lead to a 50% reduction in energy consumption of the building stock. BETA supports the Advanced Houses Program and C2000 (Green Plan) to demonstrate advanced technologies in cooperation with, and cost-shared by, industry.

In the building sector, demonstrations and technology packages are particularly important to lead and convince small firms of the benefits of new techniques and technologies. NRC, HC, PWGSC and NRCan laboratories, with private sector support or with cost-recovery, perform research on areas such as: indoor environment; residential heating systems; indoor health effects; durable buildings; lighting; and building and component performance. CMHC, PWGSC, EC and NRCan support the private sector to develop technologies and systems in areas such as: indoor environment; durable buildings; healthy housing; aquifer storage of heat and cold; and lighting systems. NRCan's Industry Energy Research and Development (IERD) program (a PERD program) can cost-share industry-initiated proprietary technology development.

The R&D programs of these departments are coordinated through the PERD Buildings Committee, ensuring an organized coherent federal activity with no duplication and much collaboration through joint work. Each of these departments, almost always acting in concert, have also established or helped to establish formal and informal S&T networks to efficiently share and disseminate information. They also participate in the development of codes, standards, performance criteria and develop technical information packages for the public. NRCan's activities are focussed primarily on energy efficiency, whereas the activities of the other departments include energy efficiency.

Agrifood and fisheries energy efficiency R&D is basically supported by PERD and some departmental "A" base. AgCan conducts almost all the work related to agrifood, and Fisheries and Oceans all the work related to fisheries. AgCan regional laboratories perform work in a wide variety of areas including: reduced tillage; integrated agriculture; primary processing; efficient placement of seed; fertilizer; and pesticide. Fisheries' R&D is contracted out to industry and universities in areas such as hull and gear design. As in buildings, these industries are fragmented and consist of many small operators who cannot afford to invest in technology development or risk trying new technologies alone. Federal S&T, including demonstrations, is necessary to convince them to apply new technologies. AgCan has established and helped to establish formal and informal networks to share and disseminate information. F&O disseminates its information through workshops and seminars. Both departments develop technical information packages, which include energy efficiency, for their clients.

Transportation energy efficiency S&T activities are performed by EC, NRCan, ND, NRC and TC. Most of their funds come from PERD, with smaller amounts from "A" base and Green Plan. TC supports work on new technology assessments and contracts out R&D in all modes of transportation in areas such as: heavy vehicle systems; truck and bus technologies; hybrid/electric propulsion; batteries and fuel cell applications; aviation services; air and ground traffic systems; navigation systems; aerospace components and advanced concepts; energy efficient wing design; composite materials; Intelligent Vehicle Highway System (IVHS); transit and traffic technologies; and rail and marine technologies. NRCan contracts out work with client industries in areas such as: particulate traps, advanced materials for weight reduction: urban transport systems; fuel cells; hydrogen systems; flywheel and battery development. NRCan's IERD program also cost-shares proprietary technology development in the transportation area. NRC performs research on diesel combustion science and fuel performance. EC performs and contracts out research related to emissions and energy efficiency. DND contracts out research in areas with can have military and industrial applications such as fuel cells and oxygen separation from air for large engines. These activities are coordinated interdepartmentally through the transportation R&D committees of the PERD network. Each of these departments have established or helped to establish formal and informal networks to share and disseminate information.

In Industry (which includes forest products, minerals and metals, food and beverage, chemical industries, electrical and electronic industries and municipal operations) the federal government plays a selective role. It basically supports energy efficiency R&D of two types: i) cost-shared development of proprietary technologies where there are high energy, economic and environmental benefits; and ii) applied research mostly in generic technology areas which have application across many sectors. IERD cost-shares proprietary technology development across all sectors in both large firms and SMEs in areas such as: paper and lumber drying; powder metallurgy; waste locomotive lube oil reclamation; power factor controllers; energy efficient motors; and battery chargers to name but a few. The Demonstration of Resources and Energy Conservation Technology (DRECT) program of (funded by PERD and "A" base) cost-shares technology development on energy-from-waste. In the generic areas, NRC performs work in alternative refrigerants and heat transfer with PERD and "A" base funds and in separation technology and tribology ("A" base). NRCan performs and contracts work on combustion of oil and gas, advanced materials, materials recycling, waste utilization with PERD and "A" base funds. EC, with PERD and "A" base funds, supports work on municipal operations such as energy efficient sewage treatment and municipal waste recycling and combustion. AECL, with PERD and UK Department of Trade and Industry funds, performs work on heat transfer as part of the bi-national Heat Transfer Fluid Flow (HTFS). IRAP, ETCP and IC's MOUs with industry also support energy efficiency related R&D in some industrial sectors. NRCan's Industrial Targeted Program, with Green Plan funds, supports sector studies, technology assessments and field trials which are cost-shared and co-managed by industry and other partners. Other departments also support a range of S&T activities other than R&D including technical information, computer programs, technology assessments, etc.

Canada taps into a vast pool of international knowledge on energy efficiency technologies by: i) participating in the S&T programs of the International Energy Agency in heat pumps NRCan and NRC), buildings (NRCan, NRC, CHMC, PWGSC) district heating and cooling (NRCan, PWGSC), energy storage (PWGSC and NRCan), alternate transportation fuels (NRCan), fuel cells (NRCan), electric vehicles (NRCan), combustion (NRC) and pulp and paper (NRCan with Paprican). and ii) participating in a Memorandum of Understanding on Energy R&D with the U.S. Department of Energy. NRCan is responsible for Canada's participation in the IEA and the U.S. DOE MOU. Canada also has considerable informal S&T information exchange mainly with the United States (all departments) but also with other countries. Scientists and engineers and other energy efficiency experts also communicate extensively with their colleagues in other countries through Internet.

In energy efficiency, the impact of a technology on one firm, one farm or one building may be small; however, the application across a sector can be very large indeed. In addition energy efficiency projects frequently have indirect benefits which include: health; water quality; soil erosion reduction; safety; and durability of structures. Since there is a variety of impacts across all sectors, all of these cannot be included here. They are therefore illustrated by examples:

- Federal funding from programs like IERD, IRAP and DRECT for proprietary technology development have resulted in a range of technologies being marketed and sold domestically and internationally.

- The impact to date of the IERD Program of NRCan (projects completed from 1977 to 1990) has been impressive. For every $1 the Program has invested in these projects, $14 per annum in direct benefits have been, and continue to be realized, by the Canadian economy. IERD has contributed $44 million to 80 projects completed in the 1977 to 1990 period. Energy saving so far is about 4.5 million barrels of oil equivalent (BOE) per annum and capital investment resulting from these projects is $169 million with domestic sales of $190 million per annum and international sales $205 million per annum. The 21 on-going projects have estimated benefits of 7.9 million BOE per annum, capital investment of $560 million per annum, domestic sales of $580 million and $2.3 billion per annum internationally. Some of the technologies developed and being developed include: air to water heat pump heat recovery system; large energy efficient electric motors; powder metallurgy parts for automobiles; reprocessing of used diesel locomotive lubricating oils; stone groundwood process controls; lubricating oils, impingement drying, diesel lubricants; fast battery charger; power electronics, high efficiency hydrogenerators; electric impulse drying of paper; and RF drying of lumber.

- The DRECT Program of EC has contributed about $8.4 million to 59 projects across Canada since 1987. Industry's contribution has been about $34 million. Direct energy savings have been calculated to exceed 470,000 BOE. Indirect savings are estimated to be three to five times the direct savings.

- The Advanced Houses Program of NRCan, funded under the Green Plan and cost-shared with industry, has challenged the housing industry across the country to be innovative. The result has been many innovative technologies which have shown the capability to reduce energy consumption by about 70%. They will be incorporated in new housing, modified as necessary for renovated and reconstructed houses and for export.

Some examples of the impact of S&T on individual technologies follow:

- AgCan (PERD) has developed a seed drill and seeding techniques that reduce the number of mechanised operations thus: reduce fertilizer demand, reduce energy demand and reduce soil erosion by reduced tillage. The seed drill seeds directly into cereal stubble without ploughing and places the correct amount of fertilizer simultaneously with the seed.

- The National Research Council, with PERD funding, is researching the properties of alternative refrigerants. With the deadline for phase out of CFCs imminent, it is necessary to find new refrigerant mixtures that can work in existing equipment without loss of efficiency, and without introducing serious technical problems. There are many candidates but their performance in existing equipment is not well known. Laboratories in many countries are studying these mixtures and exchanging data through the International Energy Agency and Alternative Refrigerants Evaluation Program (AREP). The NRC participates in this group on behalf of the

Canadian industry, sharing its information and obtaining information from other countries.

- PWGSC has developed aquifer storage technology for heating and cooling big buildings. It was able to develop this technology because it could use one of its buildings essentially as a laboratory pilot. As well, PWGSC, with PERD support, developed guidelines with the CSA on durability of buildings. These guidelines are now being reviewed by ISO as one of the two potential candidates for an international standard on durability of buildings.

- F&O, with PERD support, developed an Arctic char collector vessel to collect the catch of native fishermen in the Arctic. The vessel was designed by UBC, constructed by a Kingston Ontario company and tested by native fishermen. The vessel reduced fuel costs from $3.25 to $0.79 per pound of fish; navigates safely in difficult waters and operates in shallow waters. The vessel has proven so successful that it is now also being considered as a cheaper, safer mode of civilian and goods transport replacing aircraft between Arctic communities.

- ND has contracted the development of a temperature-assisted pressure swing absorption system (TPSA) to separate oxygen from the air. Oxygen production by existing processes is very expensive. By using waste heat, this TPSA technology could make oxygen production relatively cheap for various industrial applications such as direct oxygen feed to large burners (eliminating the production of NO_xs), and cheaper ozone production bringing down the cost of pulp bleaching and reducing chlorine use. A successful prototype has been built.

- TC, contracted the development of an electronic-based automated system named HELP (Heavy Vehicle Electronic Licence Plate) which integrates weigh-in-motion, automatic vehicle identification and communication. These allow trucks to go through weigh stations without stopping thus reducing fuel consumption as well as emissions. The systems will soon be installed.

- TC, with PERD support, funded the development of a design tool for supercritical airfoils for application in the Canadair Global Express. This allows Canadair to improve aerodynamics thus improving energy efficiency and offer a unique business aircraft flying at an altitude above the normal corridor while covering a distance of 12,000 km at a speed of 0.8 Mach with efficient fuel consumption. Canadair has now an order list for about 60 Global Express.

- NRCan, with funds from PERD, has developed a new type of oil burner head for application in domestic oil furnaces. As a result, most Canadian and US furnaces sold today contain this type of burner head which increases the energy efficiency from 60-65% to 75-90%.

- NRCan has developed (and updates) a computer simulation program called HOT-2000 which is being used as the industry standard to design R-2000 houses. HOT-2000 is marketed by the Canadian Home Builders Association.

In addition to technology development, federal experts have make considerable contributions to the development of codes, standards, regulations and technical information dissemination, and provided considerable advice on energy efficient technologies and practices to the public and to industry.

S&T Opportunities

Many opportunities for wealth creation in the short term will flow from the S&T already done. However, in many areas a major push in demonstrating and marketing technologies, spinning them off into other areas and efficiently transferring technical information will be necessary to reap full benefits. In the medium term, further opportunities to enhance wealth creation will come from the continuation of present work and the pursuit of new opportunities.

In fisheries, the accent will be on reducing energy cost and helping the industry to regain profitability and become self-sustaining. The S&T opportunities are related to development and demonstration of energy efficient fishing vessels; efficient fish finding and harvesting technology; and processing technology (including value added by product from wastes) for commercial species and underutilized or non-utilized species.

The current activities of AgCan in agrifood energy efficiency S&T provide the broad fields of endeavour for the next 10 years. Agricultural research takes time. Some specific new opportunities, which will evolve in the present program include expert systems, innovative integrated green houses, nitrogen fertilizer reduction using forage crops and food processing. The benefits will be reduced energy costs, less soil erosion, less pollution of waterways and a more sustainable agricultural system. One key area that needs further attention is the development of the Canadian equipment suppliers and their early involvement with R&D to ensure that they can supply the necessary equipment for farmers to realize the benefits. The new R&D Matching Investment of AgCan will address this issue.

The opportunities to enhance wealth generation relevant to energy efficiency in the buildings industry will stem from: i) the development and demonstration of energy efficient technologies for residential, commercial, and multi-residential buildings (NEW and retrofit); ii) manufactured housing; and iii) more integrated systems approach to building design and operation for domestic application and export. Some of the technologies include: windows; lighting systems; ventilation, heating and AC systems; hybrid appliances; heat pumps; sensors and controllers; storage systems; ice slurry systems; district heating and cooling systems; energy management systems; construction waste reduction; and the recycling of construction and demolition wastes. The benefits will be more energy efficient, better and more durable new and retrofitted buildings, more component manufacturing, and less waste and pollutants. Much of this work has already started but more effort is needed on renovation and reconstruction, waste recycling and reduction, and manufactured housing. In addition, many of the technologies and techniques developed for the Advanced Houses need to be modified for renovation. An emphasis also has to be placed on developing the component manufacturing capability by supporting SMEs with R&D and demonstration assistance as in the Advanced Houses Program. The continuing development of the knowledge base, the technical information transfer networks, the necessary codes and design tools must also be maintained.

The S&T opportunities related to energy efficiency, from a federal S&T perspective, which will enhance wealth generation in the industrial sectors are mostly based on generic technologies (their development and demonstration and information transfer) which can find applications in many sectors. These include: electrotechnologies; advanced materials; waste into value added products; sensors and controllers; heat management; systems optimization; expert systems; water removal and separations; industrial combustion systems; tribology; and natural gas technologies (such as pressurized combustion). Some effort is on-going in many of these areas but not nearly enough. There is need to develop better national coordination and information networks and do selected demonstration.

The opportunity to further enhance wealth through federal energy efficiency S&T in the transportation sector is not as promising as in some of the other sectors. Nevertheless, there are many niche areas where Canadian firms could manufacture new components, systems technologies, and future technologies such as fuel cells, batteries and variable speed transmissions. Some of these strategic technologies are being pursued but these potential opportunities need to be much better coordinated. An approach which seeks out the promising niches and assists the firms with S&T (i.e., like IERD does in the industry sector) is needed.

Across all sectors they are many niche technology opportunities and small firms with expertise requiring technology development assistance. In addition, many SMEs have technologies in non-efficiency fields which they could develop for energy efficiency. These have not being fully explored but many there are many examples to demonstrate the potential.

For energy efficiency as a whole, the key clients and stakeholders vary across the sectors. In agriculture, they are farmers, equipment manufacturers, agricultural engineers and agronomists. In the fisheries, they are fishermen on the Pacific and Atlantic coasts, the lakes, and the Arctic, equipment manufacturers and naval architects. In buildings, they are the components manufacturers, architects, mechanical engineers, owners, regulators and code makers, and building operators. In industry, they are the ancillary equipment manufacturers, the industrial plants, the plant operators, process engineers and environmental engineers. In transportation, they are the engineers and designers, the vehicle and components manufacturers, refineries, provinces, municipalities, operators, regulators, and standard makers.

Federal S&T Strategy

The actions, plans and approaches necessary to realize the opportunities mentioned before include:

- continuation of on going work approved for the next two years with some exceptions to achieve benefits from federal resources invested earlier;

- continue to develop appropriate mechanisms to work with clients and stakeholders to look at problems and opportunities from their perspective (e.g.; S&T work to be delivered with appropriate business opportunity plan);

- continued technology development through IERD (proprietary technology development across all sectors with individual firms and consortia);

- an interdepartmental and multidisciplinary program of exploratory development to build experimental prototypes of next generation technologies (preceded by preliminary market studies) and expertise with innovative firms in cooperation with universities and government laboratories;

- a nationally coordinated approach with greater industrial involvement to deal with energy efficiency of municipal operations including sewage treatment, recycling, garbage transport, garbage combustion, energy-from-waste and water treatment;

- technology demonstrations and procurement challenges to show small firms that they can introduce new manufacturing technologies and increase productivity and profitability;

- enhance international participation through the International Energy Agency and US MOU including new areas such as separations, tribology, heat exchange, process integration; develop and use mechanisms such as the Future Buildings Forum and Future Transportation Forum and national teams to get the maximum benefit from such cooperation; and enhance international technology and market intelligence gathering;

- ensure good coordination of national activities. Establish more national teams and interdepartmental teams (such as Heat Pumps National Team and Interdepartmental Committee on P&P R&D) and information/intelligence networks in areas such as separations, tribology, heat exchange, advanced materials to increase interaction and collaboration among federal and provincial governments, industry and universities;

- seek out opportunities for spinoffs from other areas such as fusion, advanced materials, electrochemistry and electromagnetic wave technologies for energy efficiency applications;

- ensure knowledge base development continues in areas such as combustion, building physics, heat exchange, separations, tribology, biotech, advanced materials, and electrochemistry in universities and government laboratories; and

- ensure appropriate mechanisms to transfer and apply information such as design tools, workshops and seminars, demonstrations, technical information packages and technology champions.

The federal government has distinct capabilities in many areas of energy efficiency which does not exist in the private sector. For example, federal laboratories have expertise in: agricultural engineering; building science; indoor environment; combustion; heat exchange; alternative refrigerants; heat pumps; advanced materials; waste water treatment; health effects; heating systems; and hydrography.

Also, federal program managers have a broad knowledge of firms in their particular sectors, of technologies available and being developed domestically in other firms and in federal laboratories and in other countries, of export prospects for new technologies, of applications of technology outside the sector, and of regulations and standards and impediments to technology applications. This kind of wide expertise does not exist outside the federal government; and federal managers use it to assist many SMEs. In areas where there is considerable industrial expertise, there is no need for federal research laboratory capabilities and for much federal program support. Such areas include: major industrial process technologies and oil refining technology.

Other Considerations

All energy efficiency activities have a positive impact on sustainability, environment conservation and carbon dioxide emission reduction. Indeed, energy efficiency is the cornerstone of most countries' approach to carbon dioxide emission reduction. Energy is vital to society and economy but it is the major polluter. Efficiency of energy use, including waste reduction and reuse, reduces pollution, reduces the costs of goods and services, conserves resources and improves health in urban areas.

Energy efficiency is national in scope in areas such as buildings and manufacturing and regionally targeted in fisheries, mining, forest products and agriculture. The federal S&T programs, ongoing and proposed, reflect this and will continue to reflect the diverse needs of these sectors and regions.

Appropriate future indicators of federal S&T success will continue to be the same as today: energy efficiency improvements; carbon dioxide emissions; industrial productivity; sales of goods and services domestically and internationally, employment, standards and codes for products and services, development of expertise and new knowledge.

Energy Efficiency Profile

Synopsis: Energy Efficiency

Importance for Wealth and Job Creation

- Canadians use $45 billion worth of energy and generate 500 million tonnes of carbon dioxide from energy production and use each year.

- Energy is a significant part of the costs of goods and services, up to 30% in some cases. In addition, there are hidden costs associated with energy use including environmental degradation and health care.

- Energy efficiency is a key element of wealth creation and the cornerstone of sustainable development and carbon dioxide emission reduction. More efficient use of energy could save from 20% - 50% of energy costs. On average, $1 million capital investment in energy efficiency creates about 24 direct and indirect new jobs, and generates $1.25 million per annum in direct manufacturing benefits and an additional $2 million per annum in goods and services. This obviously varies from sector to sector $1 million investment in industrial energy efficiency creates 1.2-2.0 times as many jobs as an equivalent investment in energy supply. Improvements in energy efficiency are expected to account for as much as 75% of carbon dioxide emissions reductions in Canada's GHG stabilization plan.

- Energy efficiency has many other benefits. It can: shift energy supply concerns to the future; reduce a wide range of wastes and associated problems and costs; produce a wide range of value-added products from waste; improve air and water quality; and reduce health care costs.

- Energy efficiency S&T provides the technological base (knowledge base, the technologies and technology infrastructure - codes, standards, networks, etc) to achieve reduced energy use.

- Energy efficiency S&T develops a wide range of goods and services providing opportunities for manufacturing, job creation, imports reduction and exports increase.

- Energy efficiency S&T is national in scope in areas such as buildings and manufacturing and regionally targeted in fisheries, mining, forest products and agriculture.

Future S&T Strategy

- The overall goal of federal S&T in energy efficiency will be to ensure that Canada has the continuing technological base needed to achieve short and long term energy efficiency strategic goals by: complementing the work of, and by collaborating with, industry, provinces, universities and other countries; selectively supporting the development of strategic technologies; ensuring the technological infrastructure is in place; and ensuring the extension of the knowledge base.

- In all sectors, there is a strategic need to seek-out and exploit opportunities for value-added products, and to transfer energy efficiency related-technologies developed in other sectors. The federal government has a key role in identifying the opportunities and assisting with their development where necessary.

- Sectors such as agriculture, buildings and fisheries, are very fragmented with many small operators. The challenge is to bring equipment manufacturers up to a higher level of technical and business sophistication to capture a large share of the domestic and international markets for both equipment and services; and to convince operators of the benefits of applying energy efficient technologies. Federal departments have accepted the challenge and are making important advances.

- Sectors such as industry and transportation are dominated by multinationals and large foreign programs of S&T. There are many SMEs and multinational companies already supplying a range of equipment and services. The challenge is work with these and other firms to expand this range of products and services and find approaches to develop and market them domestically and internationally. Federal programs like IERD and IRAP are successfully addressing this challenge.

- Continuing development of the knowledge base is needed to provide new fundamental knowledge, resolve present problems, develop codes, standards and design tools and train necessary expertise for future prosperity. The federal government laboratories have expertise in key areas of the energy efficiency knowledge base. This expertise is, in many cases, the only expertise in the country.

- Federal technical specialists have expertise in managing and orchestrating technology development and demonstrations, providing technical advice and technology and market intelligence.

- There is also a need for more skilled people to develop technology and also provide services. There is a need for more people in corporations (especially the SMEs) with both technological vision and good business acumen and a willingness to form partnerships with other firms to provide complete sales and services. Federal technical expertise has been assisting firms with forming partnerships and providing advice and information. There is need for more of this kind of assistance.

- Knowledgeable agents ("technology champions") could help SMEs to become more adept at energy efficiency S&T usage by providing guided access to assistance programs and government and university expertise, and guidance on available technology in other domestic firms and internationally (using existing mechanisms where available but also tapping the expertise of retired scientists and engineers).

- In particular areas of technology, there is a need for an expansion of effort in: end-use electrotechnologies, combustion and heat management, end-use natural gas technologies, marketable products from waste (waste needs to be considered as a valuable resource) and dewatering technologies.

- In summary, what is needed for continued progress in energy efficiency S&T is continuing renewal of the laboratory base in government and universities, expansion of cost-shared technology development programs, introduction of a specialized field trial program, introduction of an "exploratory" technology development program, and expansion of networks and mechanisms for interaction, collaboration and information transfer.

- It is an area which would yield considerable benefits from increased federal S&T investment.

Renewable Energy Profile

Sector Overview

Introduction

The renewable energy "industry" is not analogous to conventional energy supply industries. It is best defined as a group of companies that use diverse technologies and activities to produce energy by means not limited by the depletion of resources. Renewable energies are defined as solar, wind, small-hydro, biomass, geothermal and ocean energy technologies. Although large hydroelectric generation (over 20 MW) is a renewable resource, it is not usually considered, in a Canadian context, to be a member of the renewable energy industry.

Renewable energy technologies can be either fuels, heat or sources of electricity, or a combination thereof. Furthermore, the technologies vary in their applicability in the residential, commercial, industrial or transportation sectors. The premature deployment of some renewable energy projects in the early 1980's hindered, rather than helped the Canadian industry. Fortunately, the past decade has proven that renewable energy technologies are sophisticated energy systems which are technically reliable, and which have decreased enormously in cost to a point where many are now cost-competitive in specific applications.

Key Dynamics of the Industry

The emerging renewable energy industry has a small but important presence within the Canadian economy. Although renewable energy has been used for millennia, the industry is still in its infancy. Over 200 firms are active in the renewable energy industry, employing approximately 3,500 people. The industry tends to be the domain of small and medium sized industries (SMEs), with a large proportion of companies employing fewer than 10 people. The value of renewable energy sales is estimated at $620 million. (These figures exclude the fenestration industry.)

Renewable energy currently supplies 7% of Canada's total energy demand, mainly from biomass (wood and forest products' waste materials). In the Canadian industrial sector, renewables account for 16% of energy demand. Globally, renewables account for approximately 12% of demand. Canada is fortunate to have a large landmass and abundant sources of conventional fuels, but other countries are facing very different situations. In fact, many countries are facing shortages of fuels and are in need of further electricity capacity. As a result, the global market for renewables is growing at a faster pace than the Canadian market.

Bioenergy, the largest renewable energy contributor (7% of energy demand) is mainly derived from the combustion of waste materials (both liquid and solid) in the forest products industry. About 40 firms (including manufacturers) provide products and services to over 8,000 Canadian industrial and commercial users of bioenergy technologies, mostly in British Columbia and Atlantic Canada. Wood-burning appliances provide a commercial basis for another 60 firms, yielding a combined employment of about 1,300 and annual sales of about $500 million (25% in exports).

The other presently significant renewable energy is small-scale hydro with a total installed capacity exceeding 1,600 MW. Approximately 70 firms are active in the small-hydro sector in Canada, employing about 1,500 persons. The small-hydro industry has enjoyed steady growth over the years, due mainly to the reliability, cost-effectiveness and the sustainable nature of the technology. In the late 1980's, the industry had between $40 million and $60 million in sales annually. By 1991, that figure had reached $100 million, of which $35 million was in the export market. Approximately 10 firms are involved in manufacturing, including a world leader in the growing micro-hydro (less than 100 kW) world market, with the remainder working in systems engineering and installation.

The passive solar technologies are generally classified in Canada as renewable energy technologies. However, as they are closely linked to the building sector, many also consider them to be energy efficient technologies. In Canada, passive solar R&D deals mainly with fenestration and daylighting, with the market in Canada for the former valued at $1.6 billion.

The deployment in Canada of the other "unconventional" renewable energy technologies has been relatively small when compared to other sources. Nonetheless, there has been significant growth in the industry in the last couple of years, particularly in wind energy. Table 1 lists some current key statistics relevant to each technology.

Future Generation of Wealth

Renewable energy systems are now high technology processes and equipment with sophisticated designs. They are technologies for today in certain applications but more importantly, they will make an impact in the medium to long term. International bodies like the United Nations, the World Bank and the International Energy Agency have identified renewable energy as a potentially significant contributor to the global energy mix and also to sustainable development. The World Energy Council has estimated that the global contribution of renewables could increase from its present 12% to as much as 21% in 2020 if environmental concerns are taken seriously. Canadian companies, including SMEs, have

Table 1

Technology	Energy Contribution ---------- Installed Capacity	Number of Canadian Firms	Employ-ment	Average Annual Sales ($M)	Export Contribution
Bioenergy	7% of total energy demand	100	1,300	$500	25%
Small-hydro	1.5% of installed electricity capacity (1,600 MW)	70	1,500	$100	35%
Passive Solar (fenestration)	10 PJ/year	500 (180 producing high performance windows)		$1,600	
Wind	30 MW	10-15	75-100	$3 *	20%
Photovoltaics		20-30	100	$14	50%
Active Solar		10	50	$2	25%
Ocean Energy	17.8 MW	No real industry, although the world's second largest tidal plant was built in Nova Scotia in 1984 - no major difficulties encountered.			

* excludes $15 million/year investment for 2 years for construction of 2 wind farms in Alberta in both 1993 and 1994.

several unique products, technologies and expertise and a strong international reputation to capture a significant share of the global market, particularly in Europe, Asia and in developing countries. In Canada, the niche markets will grow as cost/performance continues to improve and as the sustainable nature of the technologies become more widely known to the public and to decision makers.

The use of renewable energy technologies for electricity versus non-electricity applications is an important distinction, as the market opportunities and constraints differ for the two. The changing electricity industry, with likely forthcoming deregulation of the industry, and the advent of increased non-utility generated power, will greatly increase the market for renewables. The modularity and site-specificity of renewables converge with emerging utility trends such as integrated resource planning. For the renewable energy technologies which are sources for heating and transportation fuels, the enhancement of the environment in which we live will further open the market for these clean fuels.

Canada's enormous forest resource and large agricultural production are significant potential sources of energy, in the short, medium and long-term. Bioenergy is produced from the conversion of biomass, which may be in the form of wood and other ligno-cellulosic materials, waste products from forests and mills, agricultural products and wastes or municipal wastes. Three conversion methods can be used, the most common of which is combustion. In addition, thermochemical conversion can be used to produce gaseous or liquid fuels for space heating, power generation or combined heat and power, and biochemical conversion can be used to produce fuel alcohols.

Over the past 12 years, there has been a 25% increase in the use of biomass to produce energy in Canada. There is every indication that this trend will continue, given the drive to attain sustainable development and the energy opportunities which arise from the problems associated with the management of the 30 million tonnes of solid waste generated annually in Canada (at a cost of over $1.2 billion). This financial and societal burden could be reduced if more than the present 8% of waste is combusted for energy.

The global market for ethanol as a transportation fuel is growing rapidly and Canada has some unique expertise in cellulase enzymes (enzymes that break down lignocellulosic material to glucose, which in turn is fermented to ethanol) and continuous fermentation extraction processes which increase the rate of yield. This research is at a critical stage of development and if the technology can prove to be reliable and cost-effective, there will be no further need to use arable land for ethanol production. Moreover, energy crops can be valuable alternatives for farmers who would otherwise be forced to plant less because of agricultural over-production. This factor is becoming increasingly important in North America and is already critical in Europe.

With respect to the technology of small-hydro, recent cost/performance improvements have been slow, due to efforts to simply modify large hydro's development methods and equipment to suit the smaller capacity. It has now become evident that small-hydro technology requires its own mass of expertise, equipment and standards. Recent studies have shown that cost savings of 45% are feasible from R&D for the civil works, equipment and engineering components of small-hydro development. This is significant as Canadian and foreign utilities have started programs to rehabilitate and upgrade their more attractive small-hydro plants in order to continue to provide inexpensive electricity. Other opportunities include the start up of abandoned small-hydro plants, new plants constructed at existing dams, new plants constructed to serve remote communities, run-of-river type applications and micro-hydro; the latter being less harmful on the environment. The global small-hydro market is estimated at $1-2 billion per annum.

A fast growing market segment for solar water heating systems is the aquaculture market. The incremental water temperature needed for quicker growth of such species as salmon and rainbow trout is ideally suited for solar systems. Payback periods are in the order of 2 years and productivity growth ranges from 20% - 40%. Not only will this be beneficial for the solar industry, but it will also help the aquaculture Canadian industry (an industry valued at $500 million) improve their yield, and allow the Canadian consumer to continue to enjoy high quality fish products at reasonable prices.

While significant cost reductions are needed for all components of photovoltaic energy, this strategic technology will undoubtedly play a significant role in the grid connected electricity mix in the long term. Today however, there are many niches in Canada where photovoltaics are cost-effective, particularly in remote and northern rural communities. The fragile northern ecology could also benefit greatly from such a clean energy source. Approximately 1% of the Canadian population is not connected to grid power. There is also a worldwide trend to use photovoltaics for rural and street electrification in developing countries.

The wind energy industry has constructed 3 major wind farms in the last 3 years and has plans for at least 4 more, the largest of which arises from an agreement for Hydro Québec to buy power from the construction of two wind farms, with installed capacity of 100 MW, on the Gaspé peninsula. Operation of the latter is scheduled to start in 1996 and represents an investment of approximately $145 million.

While the R&D for high performance windows for the new residential housing market is fairly complete, the commercial building and residential retrofit markets have barely been addressed, and yet these two market segments account for 68% of window sales. The commercial segment of course involves daylighting issues in addition to fenestration. By the year 2010, it has been estimated that the potential for passive solar technologies in Canada will reach 131 PJ/year, a thirteen-fold increase over today's contribution.

Sustainable Development Issues

Renewable energy technologies, by their very nature, contribute to sustainable development. Sun, wind and water are fairly ubiquitous in Canada. These energy sources produce no CO_2, NO_x, SO_x, N_2O or VOC emissions. For bioenergy to be truly sustainable, work must continue on the development of dedicated energy plantations. This includes fast tree growth via genetic engineering, harvesting methods and an understanding of the environmental implications of such activities in both the boreal and temporal forests. Additionally, as forestry management practices continue to change, research must be done on integration of the forest products' industry with bioenergy supply to ensure a continued, inexpensive source of bioenergy. The same holds true for land management practices.

Modern combustion technologies for biomass and municipal solid waste are efficient and clean burning, and they can meet strict international emission standards. While energy from waste suffers from the *not in my backyard* syndrome, the dramatic gains in air pollution control systems for energy recovery facilities have transferred the pollutants from the flue-gas to the ash. More work is thus needed on automated control systems, operator error prevention techniques and ash treatment systems.

In the small-hydro area, improvements in the design of fish diversion passages and in methods of predicting and determining fish mortality rates need to be pursued to enhance the environmental and economic status of this technology.

Although many believe that the deployment of wind farms would render large amounts of agricultural land useless, this is simply not the case. In fact, many farmers have seen the value of their land increase resulting from rental income, and have experienced less than a 3% loss in land usage as animal grazing or cultivating can take place right up to the tower structure. Visual impacts however are hard to overcome.

Characteristics of Innovation Within the Industry

Depending on the technologies and the needs, innovation ranges from advancing the state of the technology, to cost/performance improvements, to adapting processes and products for Canadian applications, to developing new uses and markets for products, to simplifying manufacturing processes.

Cheap oil prices have made the last decade difficult for the Canadian renewables industry. The fact that there still exists an industry is indication of their ingenuity. Many companies have sought and developed additional uses and markets for their technologies. For example, the cellulase enzymes perfected by a Canadian firm for hydrolysis of woody materials for fuel ethanol production are now being used to "stonewash" denim material for blue jeans, to process animal feed, and to reduce the amount of bleach required in bleaching pulp and paper by helping to break down the wood fibres. These spin-off uses of the technology is providing Iogen with sales of $10 million per year ($7 million of which are export sales). The *Solarwall*, a product developed to preheat industrial ventilation air, has been modified for use as a solar crop dryer; demonstrations are presently underway in three south-east Asian countries.

Canadian entrepreneurs are adapting and perfecting renewables energy technologies for maximum benefit to our country's needs. For example, recent legislation in various parts of the country restricting livestock from drinking out of rivers and streams has forced agricultural communities to establish water dugouts with proper aeration systems to maintain water quality. Several Alberta companies have developed small stationary and floating wind turbines to aerate the dugouts which are proving to be effective low-cost alternatives to electrical pumps. For northern applications of photovoltaics, a snow coverage of only 20% on a module can cause a 70% loss in electrical output. To alleviate this problem, a passive, low-cost technology has been developed by a Québec firm, for which a US patent and a pending Canadian patent have been issued, to reduce the accumulation of snow on modules.

In general, in the more established renewable technologies, like biomass and small-hydro, innovations have been mostly on the high technology components and the control systems. For example, Canadian low-cost, microprocessor-based load control systems for small-hydro installations now provide effective load control systems for isolated, off-grid applications, and are being sold worldwide. Innovations such as these can reduce total small-hydro system capital costs by 50%.

For the "newer" technologies like solar and wind, innovations have been focussed on improving system efficiency and lowering capital cost. For example, much of the evolution of the current solar water heating technology was pioneered in Canada with the introduction of the micro-flow concept which uses less material and less energy. Canada has a unique product in this area and holds the proprietary rights to it. Also, Canadian industry introduced the concept of integrating solar heating with existing hot water heaters. This is now recognized worldwide as the most appropriate approach. The Canadian solar domestic hot water systems employing these features are priced cheaper than many American products. The *Solarwall* of course is considered to be the world's most efficient solar air collector, and Canada also has proprietary rights to it. In 1994, the *Solarwall* was selected by R&D Magazine in the United States to receive their prestigious R&D 100

Award for the 100 most technologically significant new products of the year.

Many Canadian innovations are spearheading photovoltaic technology, despite comparatively modest financial resources. Examples include three innovative Canadian thin-film chemical bath/electrodeposition technologies (either CdTe or $CuInSe_2$) which hold promise over competing technologies, mainly attributable to their simplicity. Two of the three technologies have patents pending. A new PV array structure for roof mounted applications has decreased the cost of the structural component by over 50%, from an average $250/m² to $115/m².

The above examples are by no means exhaustive, their intent is to provide a flavour of innovation and capabilities of Canadians to capture a significant portion of the growing global renewable energy market.

Potential for S&T Advancement for Creation of Wealth and S&T Needs

S&T in the renewable energy technologies has a tremendous potential to support the creation of wealth while contributing to sustainable development. As many of these technologies are in their infancy in the product life cycle, the potential for growth is enormous. As already stated, the market for renewables is growing worldwide and Canada is quickly developing a good international reputation for innovative, reliable products. However, these firms are small and will continue to require assistance and guidance from governments to capitalize on these markets. The federal government is currently showing leadership in renewable energy R&D with a strong contract program managed by the Alternative Energy Division of CANMET, coupled with base laboratory expertise at the Energy Research and Energy Diversification Research Laboratories of CANMET as well as at the regional laboratories and national institutes of the Canadian Forest Service and the Atmospheric Environment Service of Environment Canada. International consultation and financial leverage is ensured through Canada's participation in the collaborative R&D efforts under the aegis of the International Energy Agency (IEA) in wind, solar, bioenergy and small-hydro technologies.

The types of employment opportunities related to renewable energy technologies vary with the technologies. In the bioenergy area, the non-homogeneity of the feedstock involves a considerable amount of manipulation and transfer from one process to the next. For the other renewables, each installation must be "customized" for the site in order to optimize the amount of energy output.

The industry needs government support for R&D to share the risk, to do market studies, to develop integrated systems and to develop complete goods and services packages. For the industry to grow, the cost of renewables must further decrease. Research and development is thus needed in areas such as advanced materials research, electronics, adaptation to Canadian conditions, computer simulation and automated control systems (expert systems). Additionally, renewables need to be coupled to conventional energy sources of energy as well as to each other. Examples include wind powered pumped storage for small-hydro, the use of hydrogen as a storage medium to counteract renewables' intermittent nature, and, in the North, using wind energy in the winter when the wind blows and photovoltaics during the summer sunshine hours. Work on integration is thus necessary, but such balance of system integration is a strength of the Canadian industry.

Ability of Industry to Capture S&T Advancements

Significant Canadian expertise, products, and a favourable world reputation, are available to take advantage of both the growing domestic and international opportunities but the industry needs to think in global market terms and needs governmental coordination and facilitation. While the industry is excellent at transferring technology amongst itself, it is just starting to build consortia with utilities and other decision makers and end-users which will allow for more efficient deployment of products and expertise to the marketplace. The Canadian industry is well networked internationally and is involved in many international bodies such as the International Energy Agenda, the World Energy Council, and the International Organization for Standardization. Canadian technologies and expertise have helped overcome barriers associated with operating renewable energy technologies in harsh or remote locations. This knowledge base and these products are exportable, especially to countries facing similar conditions.

Renewable Energy Profile

Assessment of Federal S&T Capabilities

Profile/Impact of Current Activities

The federal government's involvement in renewable energy technologies ensures the development and deployment of clean energy technologies that have the potential to grow in importance to Canada in the coming decades. Renewables can help attain sustainable development and can replace costly conventional fuels in Canada's remote and northern areas, including areas where the ecology is particularly fragile, as well as encourage regional development. S&T advances will play a key role in helping the young industry to grow and generate wealth.

In Canada, it is expected that renewable energy technologies will remain constant in terms of percentage contribution to the energy mix over the next 25 years, but will double in real terms due to increased interest by industry for self-generated power and increased public concern over the environment.

The principal federal government participants in S&T related to renewable energy include NRCan (CANMET, the Canadian Forest Service), Environment Canada, Agriculture and Agri-Food Canada, and to a lesser extent, Fisheries & Oceans.

- CANMET's research programs in renewable energy aim to develop cost-effective technologies to increase the contribution of renewables in the energy demand mix while minimizing environmental impact. CANMET's R&D focuses on bioenergy, photovoltaics, active and passive solar energy, small-hydro and wind energy. As a catalyst for technology development in renewables in Canada, CANMET helps industry develop technologies for their own benefit and for the public good, and acts as a bridge between industrial and environmental stakeholders.

- The ENFOR (ENergy from the FORest) program, managed by the Canadian Forest Service, is an R&D program focused on the production of forest biomass for energy, delivered through a combination of contract and in-house projects. Its objectives are to generate sufficient knowledge and technology on forest biomass production to help realize a marked increase in the contribution of forest biomass to Canada's energy supply.

- The Atmospheric Environment Service of Environment Canada provides comprehensive climatological resource data to aid in the design, planning, deployment and operation of solar and wind energy systems. This is done on both regional and site-specific scales via data acquisition, analysis and modelling. Such data is crucial for maximum energy generation from renewable sources.

- Agriculture and Agri-Food Canada and Fisheries & Oceans work respectively on crops for fuel alcohols and for minimizing fish habitat destruction in small-hydro developments.

- All federal departments carry out work related to technology development, standards development and information acquisition and dissemination.

Clients and partners for the research activities include a wide spectrum of industries, SMEs in energy and forestry, municipalities, utilities, builders, federal and provincial energy agencies, provincial forestry agencies, private landowners, international collaborators and end-users such as home owners.

Benefits of S&T in these technologies include economic growth, diversification of the energy supply, increased industrial efficiency and competitiveness, reduction of greenhouse gas emissions, exploitation of international market opportunities, and a strengthening of Canada's S&T base. Spill over benefits include the development of a young, innovative industry that is poised to take advantage of the growing domestic and foreign market for renewables. Environmental industries, the aquaculture industry and the farming community also benefit. Moreover, renewables have the following added benefits:

- production of renewable energy can provide economic development and employment opportunities, especially in rural areas. They can thus help reduce pressures for urban migration;
- growing biomass for energy on degraded lands can provide the incentives and financing needed to restore lands exhausted by agriculture, and make use of marginal agricultural land;
- elimination/reduction of the need to dispose of waste material, including municipal solid waste;
- reduced air pollution, including the abatement of climate change; and
- elimination of the need for mega-projects as most renewables are modular, and capacity can easily be increased as demand increases.

The impacts and wealth creation of work to date have been significant. While it would be impossible to cite them all, a few examples are provided:

- With financial assistance from PERD, Canadian Hydro Components Ltd. of Almonte, Ontario, has developed a low-cost manufacturing process for Kaplan type small-hydro turbine wheels, for use in the 5 kW to 1000 kW generation range. The funding helped Canadian Hydro Components design wheels measuring 630 mm and 315 mm using CAD/CAM and develop a special casting technique for their manufacturing. Since that time, the company has used the process to start manufacturing 1250 mm, 800 mm, and 500 mm wheels without further financial assistance. Revenue for the Kaplan turbines for 1993 was $1,454,000, with $340,000 attributable to the wheels themselves. Estimated revenues for these types of turbines for 1994 is $2,064,000. Canadian Hydro Components has grown from three employees in 1990, to eleven in 1994, mainly attributable to the new manufacturing process. The total cost of developing the new process was $350,000, of which PERD invested $62,000.

- The Atmospheric Environment Service of Environment Canada, with the help of PERD resources, has developed a numerical model for personal computers which helps wind energy developers choose the most effective sites for wind turbines. The model, known as MS-Micro, produces estimates of wind speed over complex terrain which is important for determining the economic viability of wind energy. The actual location of a wind turbine is crucial in order to achieve maximum energy output given that the energy from a wind turbine can increase by 33% with an average increase in wind speed of only 10%. Canadian wind energy developers used MS-Micro for the siting of wind farms in Alberta, Saskatchewan and Québec. Version 3 of MS-Micro has generated $6,000 in revenues between 1990 and 1993 with sales in 13 countries. Between 1986 and 1990, earlier versions were sold for a total of $11,000. PERD has contributed $10,000 to the development of the model, while other sources contributed $30,000.

- Lafarge Canada of St-Constant, Québec, with CANMET support, has developed a process to use old automobile tires as a fuel supplement in their cement kiln. The operation involves mid-kiln injection of whole tires. There is no need to shred the tires prior to use, nor is cement quality compromised. Recent air emission tests could not detect any adverse effects to air quality. As a result, Lafarge received an operating permit from Environment Quebec to use the mid-kiln injection process. Lafarge's initial plans are to consume tires from old abandoned tire dumps on a normal production basis in June, 1994. The company expects to use over 1 million tires per year, amounting to over 50,000 barrels of oil equivalent. PERD contributed $300,000 to the $2 million project.

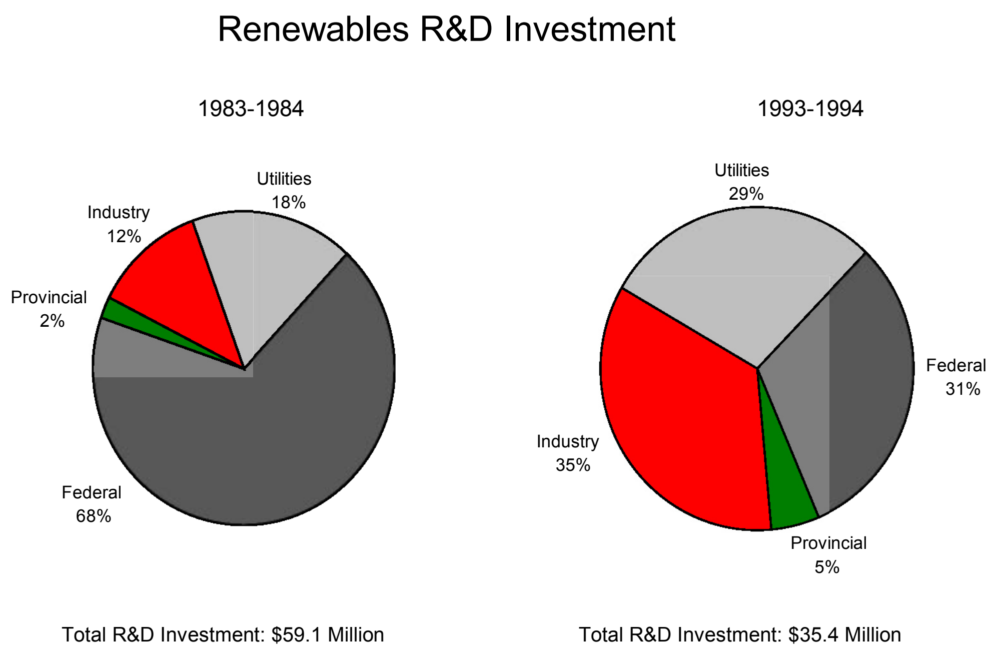
- The Alberta Renewable Energy Test Site, with co-funding from PERD, helps manufacturers of wind and photovoltaic water pumping systems to evaluate their equipment by subjecting them to performance and reliability tests. Two Saskatchewan companies, Dutch Industries of Regina and Koenders Manufacturing of Englefeld, have taken full advantage of the services offered at the Test Site. Dutch Industries virtually perfected their wind powered water turbine, the Delta 16, at the site. In 1992, Dutch Industries exported a total of 500 Delta 16 turbines, valued at $700,000, to the USA and Africa. Koenders Manufacturing developed a small wind-pumper at the site and have sold 1,200 systems valued at $690,000. Koenders Manufacturing is also establishing a dealership in Eastern Canada, and has plans to expand to the USA in 1994. Collectively, these two companies have to date created 15-20 full time jobs in Canada. Investment at the Test Site is estimated at $150,000 per year, a third of which is funded by PERD.

R&D Investment Trends

In 1983, a total of $59.1 million dollars was invested in R&D directed at renewable energy. Figure 11 shows the breakdown of investment by the four parties. The federal government was the largest contributor, spending $40.3 million. The next largest contributor was the utility companies which provided $10.7 million. Industry invested $7 million while the provinces contributed $1 million. The main areas of R&D were bioenergy, solar energy, and wind energy.

In 1993, two decades after the first oil embargo and one decade after the termination of the National Energy Program, total investment fell to $35.4 million. The federal government's investment fell dramatically to $10.8 million; this was a decline of 73.2% from 1983, and was for deficit reduction reasons. Although the overall investment in renewables was less in 1993 than in 1983, the sharing of the R&D between the federal and provincial governments, utilities and industry became more equitable. The provinces became more active, contributing $1.8 million. Industry's contribution increased to $12.3 million, an increase of 43%. The utilities contribution to this area of R&D fell slightly (by 2.8%), from $10.7 million to $10.4 million. The total decline in R&D for renewables can be attributed to the federal government's decline in investment while the provinces, industry and utilities combined spent an extra 5.7 million in 1993 than they did in 1983.

Renewable Energy Profile Figure 11



Nature of S&T Opportunities and Strategies

The guiding strategy for federal S&T activities in the renewables area is built on a solid track record of forming alliances with public and private sector partners for an effective and efficient delivery of programs. A consortium-type approach addresses common concerns and allows the opportunity to build multi-disciplinary teams of industry, government, academia, the users, the public and other stakeholders. The emphasis on cost-shared and task-shared work ensures that R&D undertaken is relevant to industry needs, shares complementary resources and fosters creativity and innovation.

The main objectives of all renewable energy technologies are to reduce costs in order for them to become more cost-competitive with conventional energy sources. The needs across the various technology areas are however different.

In the bioenergy area, an important focus will be on the feedstock. To maximize the amount of energy output from this important source, in the short-term, research must be done on integrating the forest products and energy industries harvesting and collection techniques in order to benefit from the substantial amount of residues not currently being utilized. However, in the medium to long-term, the increased worldwide demand for forest products coupled with environmental pressures on the management of the forest resource, will make the forest products industry more efficient, making more use of residues which would otherwise have been available for energy. Already we are seeing the beginning of this trend; to counteract this, we must ensure that the R&D is in place today on dedicated energy plantations.

Biomass feedstock preparation is another key opportunity which is needed to improve fuel quality and handling properties. Significant cost-effective gains can be made as the efficient conversion of biomass to energy is highly dependant on feedstock size, homogeneity and moisture content. For example, the development of advanced biomass drying technologies will result in improved feedstock quality which will reduce handling and conversion costs. Improvements in feedstock quality can reduce the cost of bioenergy by 25%.

The focus of S&T activities in biomass combustion will be on advanced combustion methods, such as pulverized wood firing and fluidized bed combustion and on techniques for converting municipal wastes to energy. Significant efforts are needed to develop new equipment to best respond to new sources of biomass materials such as de-inking sludges from recycled materials. Efforts will also be directed on the development of small self-contained biomass fired generation units, particularly under the 1 MW size range, to access the emerging district heating and remote community markets. For energy from waste, automated emission control systems, operator error prevention technologies and ash treatment technologies are needed.

Gasification of biomass for electricity generation has been identified as an important area and work will continue on biogas clean-up. The advancement of fuel ethanol production from woody material will eliminate the need for using arable land for fuel production purposes and provide alternatives for farmers who would be forced to plant less due to agricultural over-production.

For small-hydro, capital cost reduction of 16% - 19% would double the economically viable potential of the resource in Canada. The best way to reduce these capital costs is through research and development with a focus on more cost-effective turbines, generators and control systems, and innovative, cost-effective civil structure design for small-hydro power plants which will minimize the impacts on fish and the environment. In order to achieve the latter, the development of reliable environmental impact assessment methodologies and tools, especially as they relate to the protection of fish and fish habitats is needed.

In the active solar area, low temperature heating applications which will have the greatest impact include ventilation air heating for commercial/industrial buildings, residential water heating, and heating for aquaculture. Advanced material R&D and processes are needed for these applications to lower the cost and increase the reliability of this niche technology. The passive solar area, after successfully developing products for new construction, must now turn its efforts to the residential retrofit market, which could allow some simplification of heating systems, and to the commercial building sector.

Cell research will continue to be the most critical area of research in photovoltaic technology as cells represent 50% of the total system cost. Despite comparatively low financial resources, Canada has three unique, promising cell technologies which have potentially significant market potential. In the balance of systems area, further modelling development is needed to assist system designers, already existing foreign technologies must be adapted for Canadian applications, and improvements in photovoltaic energy storage systems must be made, particularly for cold environments.

In the fast growing wind energy area, better information and prediction methods are needed for the wind resource. This is best achieved through a combination of real time data collection and simulation software. On the equipment and process side, continued improvements of small size (50 kW to 80 kW) wind turbines and promotion of their use among potential users is necessary. Today, the installation of such turbines makes economic sense for such markets as remote, off-grid communities and agri-business farmers connected to the main grid. Also, S&T is needed to assist the industry to develop cost-competitive wind turbines in the 250 kW to 699 kW range suitable for windfarm applications and to continue to support the design and development for arctic applications including the High-Penetration-No-Storage wind/diesel concept which has considerable potential to replace diesel generators in northern communities (the Canadian Electrical Association has identified 108 diesel plants in northern Canada which could be potential sites for wind-diesel replacement).

In the country, scientists and engineers at CANMET are the national experts in the renewable energy field and act as catalysts and provide leadership in R&D partnerships. They contribute to a national network of innovation, stimulate investment in higher-risk, higher-payoff R&D and provide support for longer-term basic research. The Canadian Forest Service's ENFOR program is the only comprehensive R&D program in Canada on the production aspects of forest biomass for energy. The capabilities required to undertake the ENFOR program are distinct from, but closely related to, those required for undertaking S&T in more conventional forest management. The comprehensive CFS S&T facilities and expertise across the country can thus be applied to forest energy issues and opportunities in a highly efficient manner and at minimal incremental cost. The data acquisition and modelling work provided by the Atmospheric Environment Service is unique, given their expertise and their historical databanks.

These three federal government groups have key S&T capabilities in all areas of renewable energy in their laboratories in the form of sophisticated, specialized facilities and in the knowledge and expertise of its research scientists, engineers, and their coordination and management systems. The capabilities are dispersed across the country, but they are linked together by the federal programs through coordination and leadership. These federal S&T activities complement the capabilities of the industry and provincial governments and enable the federal government to fulfil its vital leadership role for the benefit of all Canadians. All of the research undertaken is guided by Technical Advisory Committees composed of industry, academia, and federal and provincial agencies. If it were not for the federal expertise and facilities, mainly critical S&T capabilities simply would not exist in Canada today because of the size and structure of the industry. The federal involvement in this area will allow for Canadian, rather than foreign, industry to play a key role in Canada's sustainable development efforts.

Future client groups will most likely expand from the present as the industry and the applicability of renewable energy technologies grows.

Nature and Feasibility of Federal S&T Strategy

In the renewables area, the federal government currently plays a strong leadership role for the small industry. S&T activities are multidisciplinary and involve several departments and agencies. The federal interdepartmental Program of Energy Research and Development (PERD) ensures coordination and focus in renewable energy R&D activities and provides a mechanism for realigning the S&T activities of the departments involved to deal with emerging issues.

The federal S&T infrastructure complements the work being done by utilities and industry. However, these areas are of strategic importance for the national interest and include the environment, sustainable development, northern and remote community self-sufficiency and long-term/high risk technologies. The nature and size of the private sector in the renewables area does not allow it to invest in the sophisticated equipment nor undertake much R&D on its own. Up until a few years ago the critical mass in renewable energy expertise resided mainly within the federal government but successful efforts have been underway for a few years to transfer and deploy as much of this expertise as possible to the industry in order for it to become self-sustaining. The industry, although still small, now has some unique, innovative products and expertise which it can market abroad.

Renewable energy technologies are currently at a critical stage of deployment. Integration of the technologies, both amongst themselves and with conventional energy sources, is needed. While the expertise exists across the country, maximum collaboration is required to facilitate this integration. This role is best played by the federal government as it is presently the sole organization with the domestic and international network, proficiency and willingness to establish the required R&D consortia.

S&T related to standards and codes development is also the responsibility of the federal government and will grow in importance as more renewables are deployed. Moreover, standards and codes have the ability to affect behaviour and normal practices and can themselves stimulate deployment; providing the S&T infrastructure is well developed.

To derive maximum benefit from renewable energy S&T, the public, and all levels of decision makers must be further educated on the reliability, applicability and affordability of these technologies. Skilled tradespeople will also have to be trained in maintenance of these systems.

Other Considerations

Renewable energy technologies are one of the building blocks of sustainable development and help to conserve Canada's natural resources for the prosperity of future generations. They will not replace conventional sources of energy, but will rather complement them.

As the majority of harnessable renewable sources of energy are in non-urban locations, the development of these resources will lead to regional development, reduce the pressure for urban migration and create high technology jobs in these areas.

CANMET, Environment Canada and the Canadian Forest Service have developed extensive international contacts in R&D and standards development through international bodies like the International Energy Agency (IEA), the World Bank, the World Energy Council, and the International Organization for Standardization. Among the benefits from Canada's involvement in such organizations include the ability to assist industry in both acquiring and marketing technologies and related expertise and services in other countries, comparing our capabilities and technologies with other participating countries, pooling of data and experience, focusing and coordinating Canadian S&T activities in order to avoid overlap, and more rapid use of S&T results. Other benefits include access to facilities not available in Canada, links forged between the private and public sectors, and considerable financial leverage.

Canada is uniquely positioned in the world as it can use the expertise it has acquired domestically and though the IEA R&D network over the last 20 years, and market it to other countries belonging to the Asia-Pacific Economic Cooperation where renewable energy technologies will undoubtedly play a major role in the development of the south Pacific/Asian region where energy shortages are predicted.

The S&T organizations in renewable energy already have in place, within their own departments, and through PERD, performance measurement systems to monitor their collaboration with industry. These include the amount of cost-shared and task-shared work, revenues from intellectual property, licences, publications, and patents. The future impact of federal S&T in renewable energy technologies will be build on these measures and extend to the amount of deployment of the technologies, wealth creation, and to the extent by which they supersede old technologies.

Renewable Energy Profile

Synopsis: Renewable Energy

Importance for Wealth and Job Creation

- Renewable energy will be one of the main building blocks for sustainable development.

- The reliability of the technologies and their cost-performance have matured immensely over the last decade.

- The industry currently employs 3,500 people and enjoys over $600 million in sales with over 25% in the export market. Small, innovative companies dominate the industry.

- Given the site-specificity and non-homogeneity of the renewable resources, the jobs in the industry are sustainable and many are in rural areas.

- The global market for renewables is growing rapidly. Annual world energy demand could double by the year 2020, and renewables could account for as much as 21% of this demand, with the greatest demand being in the south Pacific and Asian countries. As a member of APEC, Canada, with its favourable world reputation, its quality products and its expertise is uniquely positioned to capture a major portion of the emerging market.

- The industry is finding innovative spin-off uses for its technologies, including solar heating in the aquaculture industry and for crop drying, and for environmentally friendly replacements for bleaching agents in the pulp & paper industry.

Future S&T Strategy:

- Collaborative S&T with stakeholders is the key to lowering the cost of renewable energy technologies and to couple high technology with environmental technology.

- Canada's enormous forest resource can grow in importance as a source of renewable energy but R&D on integrating the forest products and energy industries' harvesting and collection techniques is needed for the short term and dedicated energy plantations will be needed for the longer term. Also, improvements in feedstock quality, such as size, homogeneity and moisture content, can reduce the cost of bioenergy by 25%.

Renewable Energy Profile

- Energy recovery from waste can contribute to sustainable development and solve disposal problems and all its associated monetary and societal costs. More efficient conversion technologies, along with improved automated emission control systems, operator error prevention and ash treatment technologies should be developed.

- Innovative and standardized civil structure designs and construction techniques for small-hydro power plants will render the technology more cost-effective and minimize the impacts on fish and the surrounding environment.

- Canada's wind resource is said to be one of the best in the world, however better information on, and prediction methods for the wind resource are needed for siting wind turbines.

- Advanced materials and simplified manufacturing processes are required for the solar and wind energy technologies.

- All renewable energy technologies need codes and standards to ensure public safety. The S&T needed for them will grow in importance as the deployment of renewables increases.

- Federal investment in renewable energy S&T is at a bare minimum and should be increased if Canada is to obtain sustainable development and the viable wealth generation benefits of a young, growing industry. The current coordination structure through PERD should be maintained. Some consideration should be given to establishing an additional innovative challenge program cost-shared between government and industry.

- An industrial development strategy for the renewable energy industries is required, addressing national and global markets. This would help further focus the S&T investment, both in terms of technology choice and cost reduction, and accelerate the deployment of existing technology.

Alternative Transportation Fuels Profile

Sector Overview

Introduction

Alternative transportation fuels (ATFs) are substitutes for gasoline and diesel fuel in transportation vehicles. Propane, natural gas, oxygenates (methanol and ethanol), electricity and hydrogen are all ATFs. Reformulated gasoline and reformulated diesel are not ATFs. These products are produced from the same components as regular gasoline and diesel. Furthermore, they are used in conventional vehicles, just as regular gasoline and diesel are.
Currently, propane, natural gas and ethanol account for 1.7%, 0.2% and 0.03% respectively of transportation energy demand in Canada. This represents about 0.4% of total Canadian energy demand. Environmental issues are the major driving force for furthering the market penetration of ATFs.

Key Dynamics of the Industry

The growing ATF industry already stimulates the output of many goods and services. The goods include: engines, ATF vehicles, components, advanced batteries, fuel cells, fuels (i.e., propane, natural gas, hydrogen, oxygenates and their derivatives), and compressors and associated hardware for fuelling stations. ATF services include vehicle conversions, research, information, refuelling station design and construction, maintenance and consulting to the transportation industry. The Canadian ATF industry, which has a good, well-earned reputation, provides these goods and services nationally and internationally.

In total, the ATF industry contributes over $400 million and over 2,000 jobs to the economy. Exports contribute between $15 and $20 million per year. These figures do not include research and production of ATF vehicles by the "Big Three" USA/Canada auto makers (GM, Ford and Chrysler) nor exploration and production of the fuels, except non-fossil, electrolytic hydrogen.

Propane and natural gas are the most well known and widely used ATFs. Unlike, traditional transportation fuels, propane and natural gas are gases at atmospheric pressure. For their use in transportation, they are stored under pressure to reduce their volume.

In 1993, propane and natural gas transportation demand was 1.3 million cubic metres and 5.4 million cubic metres respectively. With the assistance of federal and provincial incentives, there are now over 145,000 propane vehicles operating in Canada, supported by some 3,000 propane fuelling stations. There are some 25,000 natural gas vehicles, supported by 117 public and 67 private fuelling stations. Some 70 natural gas transit buses are also operating in Canada.

The oxygenates are methanol and ethanol (i.e., alcohol fuels) and their derivatives. They are less well known and less commonly used for transportation purposes. Unlike propane and natural gas, methanol and ethanol are liquids under normal atmospheric conditions. This characteristic means that they can make some use of the existing gasoline and diesel fuel distribution system and infrastructure.

Methanol and ethanol can either be used in the pure form or as additives. The use of pure methanol or ethanol is currently limited (i.e., Indy racing cars use pure methanol). Methanol and ethanol are more commonly used as additives to gasoline or diesel.

Methanol is an efficient and clean-burning fuel. As a transportation fuel, its applications are as: i) a raw material in the production of the high-octane gasoline additive MTBE (Methyl Tertiary Butyl Ether); ii) a substitute for diesel fuel in heavy-duty vehicles, particularly buses; and iii) a neat (100% methanol) or near-neat (85%-methanol gasoline blend called "M85") alternative to gasoline. Methanol is traded worldwide as a petrochemical feedstock, with a current demand of more than 21 million tonnes. Canada produces roughly 10% of this world demand. Methanol, often referred to as "wood alcohol," can be produced from wood, natural gas (the lowest cost), coal, garbage or agricultural waste.

Methanol's development as a vehicle fuel is still in the market demonstration phase in Canada. Currently, 118 methanol vehicles (including 18 transit buses) are in use. There are two methanol fuelling stations in British Columbia, one in Alberta and one in Ontario.

In Canada, ethanol is produced almost exclusively by fermenting grain. It can also be produced by fermenting corn or sugar cane. While it is currently more expensive to produce than gasoline, considerable potential exists to reduce ethanol production costs using wood or other wastes, which are lower-cost feedstocks. Low-level ethanol blends (gasohol) is marketed in the four western provinces and Ontario, where they benefit from provincial tax relief. Canada's two fuel-ethanol producers (located in Minnedosa, Manitoba, and Kerrobert, Saskatchewan) produce about 21 million litres of ethanol annually. The ethanol is used in 10%-ethanol gasoline blends sold by Mohawk Oil in western Canada and UCO in Ontario.

Hydrogen and electricity are in their formative stages as transportation fuels. Hydrogen can be burned directly as a fuel or can be supplied to a fuel cell. The hydrogen fuel cell produces the electricity used to drive a vehicle's electric motor. The electric grid can be used to directly charge a battery-driven vehicle. Hydrogen production activities are in Quebec and Ontario while batteries and fuel cells are in Quebec, Ontario and B.C.

Future Wealth Generation

ATF use in Canada will grow slowly to the year 2000. More than half of the growth will be in the use of propane, followed by increases in the use of natural gas, and oxygenates in gasoline and diesel blends. The export market will grow considerably because of aggressive alternative fuels policies in the United States and other countries.

By the year 2000 the ATF industry could quadruple in size, with a large portion of the increase coming in the export market. The North American market for zero emission vehicles (i.e., fuel cells, batteries, etc.) and ultra low emission vehicles could exceed $1 billion in 2000.

A determining factor in the growth of the ATF industry will be the success in overcoming the consumers' hesitance to accept new or little proven technologies. The limited refuelling network for ATFs is also an impediment to consumer acceptance. Of importance to the expansion of the ATF market will be conversions and, of greater importance, the introduction of original equipment manufacturers' vehicles designed specifically to use alternative fuels. In North American, the production and marketing of original equipment manufacturers' ATF vehicles have been limited and sporadic. North American vehicle manufacturers that still offer (or plan to offer) propane, natural gas and methanol vehicles are expected to direct sales primarily at fleet purchasers. A small amount of expected growth is that Toronto and Hamilton plan to purchase, respectively, 100 and 40 Canadian natural gas buses.

When produced in volume, original equipment manufacturers' ATF vehicles are expected to be significantly cheaper than the purchase of gasoline- or diesel-fuelled vehicles converted to ATF use. Combined with current and anticipated fuel price differentials, this lower cost will improve the payback on investments in ATFs. Moreover, it may become increasingly difficult to convert gasoline engines, as conversion equipment must be compatible with the sophisticated electronic control systems of new vehicles. This reinforces the view that the future of alternative transportation fuels lies with original equipment manufacturers.

In the longer term, environmental considerations will have an increasingly important influence on the future of ATFs. For example, California's severe smog problems have created the need for Ultra Low Emissions Vehicles and Zero Emissions Vehicles. By 1998, regulations will require that 2% of the new cars sold in California be zero-emission vehicles; this requirement will rise to 10% by 2003. Although it is too early to say what the preferred transportation fuel will be in California, these regulations could increase the availability of ATF vehicles and reduce their cost. Further, the U.S. *Energy Policy Act* of 1992 requires that federal fleets and centrally-fuelled private fleets purchase a specified proportion of ATF vehicles beginning in 1994. The California and federal programs could provide a major impetus to ATF use in the U.S., possibly resulting in sales of a million ATF vehicles by 2010.

Sustainability Issues

Concerns about the environmental impact of continued use of traditional petroleum transportation fuels have resulted in an increased scrutiny of alternative fuel vehicles. Emission standards will be the major driving force for furthering the market penetration of alternative fuel use in transportation.

Many factors influence vehicle emissions, and the results of emission testing have not as yet been definitive. However, testing has shown that:

- propane and natural gas vehicles can reduce greenhouse gas emissions by 25% and 10% respectively; methanol produced from natural gas provides no greenhouse gas emission reductions; and alcohol fuels produced from biomass have the potential to provide reductions, particularly as production technology matures, although studies have shown significant greenhouse gas (GHG) emissions from the industrial production of biomass;

- natural gas, methanol and propane all have the potential to reduce emissions of nitrogen oxides and volatile organic compounds, which lead to urban ground-level ozone formation (urban smog); ethanol blended at 10% in gasoline does not affect nitrogen oxides or volatile organic compounds emissions when gasoline is adjusted for vapour pressure; and

- ATF vehicles have the potential to reduce emissions of known carcinogens such as benzene and 1,3-butadiene.

Alternative Transportation Fuels Profile

Both natural gas and propane vehicles have been designated as "Inherently Low Emitting Vehicles" by the U.S. Environmental Protection Agency, as their closed fuel systems eliminate evaporative emissions.

Compared with gasoline vehicles, flexible fuel vehicles have displayed a significant benefit in emissions when operated on M85. These vehicles can meet the Low Emission Vehicles standards on M85 without resorting to advanced exhaust after-treatment technology.

Dedicated alcohol fuel (M85) vehicles could potentially equal or better the emission performance of a flexible fuels vehicle. However, when compared to a flexible fuel vehicle operated on M85, the benefits are marginal at best. Dedicated alcohol fuel vehicles could see limited penetration post 2000 if an adequate M85 supply infrastructure is developed.

Dedicated compressed natural gas vehicles have also displayed emission levels capable of meeting Low Emissions Vehicle standards without any exhaust after-treatment. However, this is not true for dual fuel compressed natural gas vehicles based on after-market conversions. Because of the bulkiness of the fuel storage tanks, the greatest penetration of compressed natural gas vehicles could likely occur in the full-size cars and light-duty trucks and vans. Propane powered vehicles have also demonstrated very low emissions.

Electric vehicles continue to be the only option to meet the Zero Emissions Vehicles standards. Methanol, ethanol, propane and natural gas will not provide the environmental or economic benefits needed to meet long-term environmental goals.

Overall, the growing concern over greenhouse gasses will push Ultra Low Emissions Vehicles and Zero Emissions Vehicles to further prominence.

Characteristics of Innovation in the Sector

The cost and efficiency of our conventional gasoline and diesel transportation fleet reflect a century of technology development. In contrast, the energy, environmental and economic benefits of ATFs need much more technology development to bring them near to an equal level of maturity. The federal government realizes this, as shown by various ATF R&D programs.

These research activities should continue, with emphasis on several areas that reflect the characteristics of innovation in the sector:

(i) lowering the costs of ATFs - lower costs of conversions and original equipment (onboard storage, cold-weather performance, batteries of higher energy density) and costs of fuelling systems (including on-board reforming of a hydrogen carrier);

(ii) enhancing the many environmental advantages which ATFs have over the conventional fuels will open large market opportunities; areas of interest include ground-level ozone-forming emissions, unburnt methane release (methane is a much more potent greenhouse gas than carbon dioxide) and nitrogen oxides emissions;

(iii) identifying and reducing the risks to safety - areas include the flame luminosity of methanol and the integrity of natural gas onboard storage tanks; and

(iv) positioning Canadian industry for the growth of Ultra Low Emissions Vehicles and Zero Emissions Vehicles - the market in Canada and especially for export offers many opportunities for Canadian companies to excel, but time and patience is needed for their development - successful examples already exist, such as Electrolyser cells for hydrogen production.

Potential for Technical Advancement to Support Wealth Creation

The introduction of air emissions standards in the U.S. has renewed interest in electric-powered vehicles. The transition to zero emission vehicles will likely take 30 to 40 years. In the next ten years, zero emission vehicles will mean battery-powered vehicles. Ultimately Zero Emissions Vehicles will be powered by some combination of batteries, hydrogen fuel cells, flywheels or ultracapcitors. Ensuring this transition will require significant R&D efforts.

Currently, research on advanced batteries focuses on resolving problems such as short battery life, limited range, long recharge times, high operating temperatures and, above all, excessive weight and cost. Addressing these limitations will ensure a wider acceptance of electric vehicles and hybrid variations.

Significant research is under way on hydrogen. Major breakthroughs in areas such as the cost-effective production of hydrogen fuel, fuel-cell technology and fuel storage could propel hydrogen to compete as a transportation fuel. Canada is a world leader in the development of hydrogen vehicles. A Canadian company, Ballard Power Systems, is building a hydrogen bus for a target commercialization date of 1998. The company is currently demonstrating a fuel-cell bus in service with British Columbia Transit.

Ability of Industry to Capture Benefits

For the most part, this industry is fully capable of capturing the benefits offered by ATFs. The "Big Three" Original Equipment Manufacturers have indicated their abilities to meet consumer demands for ATFs. While the original equipment manufacturers have the ability to meet this demand, proving the technical reliability of these vehicles will require continued government support. Such support ensures that the original equipment manufacturers' Canadian operations are not marginalized in corporate decisions to meet new generations of ATFs; this is an important consideration. As well, fostering the shift from the near term technologies, such as propane and natural gas, to hydrogen and fuel cells by the year 2000 will require financial support.

In Canada, considerable progress has been made in the development of the hydrogen, battery and fuel cell technologies. Canadian-developed fuel cells are among the most efficient and cost-effective in the world. Close collaboration between researcher in industry and universities and between governments, has enable Canada to maintain its leading edge in this rapidly changing industry.

Assessment of Federal S&T Capabilities

Role of Federal S&T

The strategic thrusts of ATF research strategic thrusts are to promote substitution and efficiency in the transportation area with a focus on:

- economic benefits;
- environmental protection, health and safety;
- energy security and diversification.

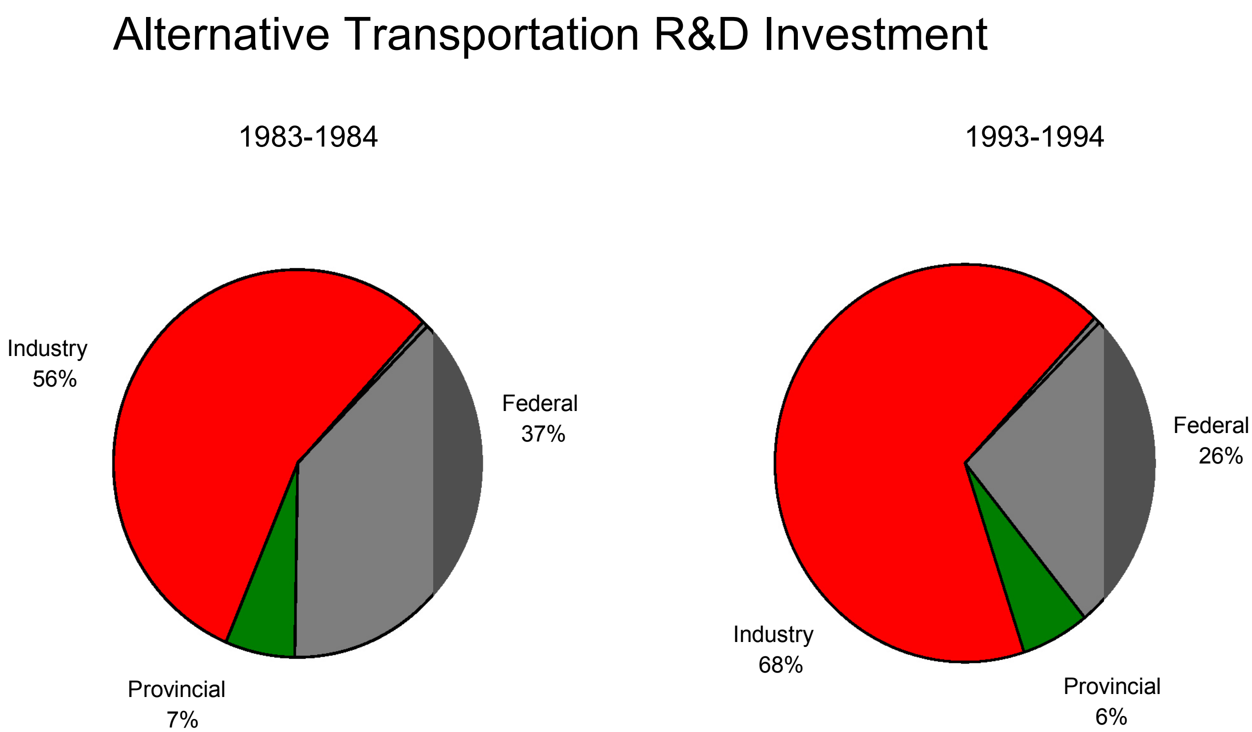
The overriding strategy is to work in collaboration with industry and the provinces to provide federal leadership in S&T development. The federal governments role is to coordinate, network and facilitate S&T activities. As well, the federal government plays an important role in providing knowledge and technical expertise to the various organizations involved in trying to introduce alternative fuels. Federal participation brings a national perspective to the transportation field.

R&D Investment Trends

In 1983 a total of $110 million was invested in R&D in this area. Figure 12 shows the percentage contribution of the federal and provincial government's to alternative transportation research in 1983 and 1993. The federal government spent $41 million while the provinces spent $7.1 million. Industry invested some $61 million. Most of this research was directed towards alternative fuels such as natural gas, propane, ethanol and methanol. As well, research into batteries and energy storage was initiated during this period.

In 1993, the total R&D investment was cut, for deficit reduction reasons, to some $54 million. The federal government contributed $14.1 million which is 65.6% less than in 1983. The provinces followed a similar path, contributing 53.5% less for a total of $3.3 million. Industry's investment declined by some 35% to ($37 million).

Figure 12



Nature and Feasibility of Federal S&T Strategy

Profile/Impact of Current Activities

The alternative fuels industry involves many small and medium enterprises who lack the critical mass of researchers and facilities to achieve S&T advancements. Besides developing the technologies to use alternatives in vehicles, there is a major need for S&T advancements in the fuelling infrastructure.

Although the automobile industry is large, it is the small and medium enterprises that provide the component parts to the vehicle original equipment manufacturers. The automotive parts industry is fragmented and in need of major support in maintaining its technology competitiveness. Maintaining this competitiveness is key to the continued viability of this industry. Many of these parts manufacturers are located in Ontario and must compete with foreign companies for original equipment manufacturers' orders.

Alternative Transportation Fuels Profile

The general nature of government ATF activities is to work with industry to promote the development and use of alternative energy technologies in Canada's energy economy; to remove technical and institutional barriers to facilitate the introduction of alternative transportation energy technologies; and to provide technical advances on the efficient and environmental use of existing fuels.

Current R&D efforts spans several alternative fuel options for the short, medium and long term. There is a concerted effort to maintain a logical balance between exploratory, incremental and strategic research. Improved efficiency and the increased use of gaseous fuels and oxygenates (alcohol fuels) are likely to have the greatest impact in the short term (five years). The R&D strategy will be primarily industry-driven and incremental, with emphasis on applied research to improve productivity and reduce costs, and on field trials.
In the efficiency area, activities will focus on developments with the automobile and trucking industry to provide support to policy development with respect to vehicle efficiency capabilities. A primary thrust will focus on advanced materials for use in vehicles. Development of a flywheel energy storage system for use in hybrid vehicles will also be a major thrust of the S&T activities. This latter effort has great potential to bring a Canadian developed technology to the forefront.

In the medium term (up to 15 years), electric vehicles will play a significant role in reducing greenhouse and toxic emissions. Zero Emission Vehicles will create opportunities for wealth generation. The strategy is to support R&D on battery development, hybrid-vehicle modelling and development, infrastructure development and in field trials to provide input to policy.

Longer term R&D will be in the area of hydrogen and fuel cell technologies. Work will be exploratory and applied research with industry, industry associations and universities. An exception to long term applications is the early use of solid polymer electrolyte fuel cells in a bus. Because of CANMET and other government support, Ballard Power Systems is a world leader in solid polymer fuel cells. Continued support to this work is essential to maintain this advantage and to bring a Canadian technology to the world marketplace.

Impacts and Benefits

The impact of this S&T activity is manifested in the growing use of alternative fuels and emergence of an ATF industry. Canada is becoming world renowned in proton exchange membrane fuel cell development, natural gas vehicle technologies and electrolysers for hydrogen production. Canada is a world leader in electrolytic hydrogen production technologies. The Electrolyser Corporation is an established supplier of electrolytic hydrogen production plants world wide, exporting to 90 countries.

As well, several companies, such as EDO, GFI, Steel Cylinder Corporation, Fuelmaker and Sherex have established manufacturing facilities in Canada for the manufacture of ATF components. These companies also export their products. Canadian consulting firms are also active in the international market advising and planning ATF programs.

There have been several important achievements:

- the world's first fuel cell powered transit bus was launched by Ballard Power Systems of North Vancouver, B.C. CANMET was instrumental in the initiation and direction of the project, providing technical assistance and funding support of $1 million for the $5 million project. The technology is now being transferred to the development of a full-size 12-metre (40-foot) bus, with South Coast Air Quality Management District of California providing $1.3 million. California is very interested in the Zero Emission bus and the bus may find its first application in that state.

- a project has been initiated with Inco Limited to test a state-of-the-art electric vehicle manufactured by Chrysler Corporation in Windsor. This TEVan currently uses nickel cadmium batteries, with Inco-produced nickel powders. It is anticipated they will be replaced with nickel metal hydride batteries, with advanced nickel electrodes produced in a joint Inco/CANMET project.

- a Ford Ecostar electric vehicle will be tested by the Municipality of Metropolitan Toronto. This advanced electric vehicle is powered by an ABB Advanced Battery Systems sodium sulphur battery.

- CANMET supported GFI Control Systems Inc.'s testing program to finalize their qualification as the "Conversion Kit" QVM (Qualified Vehicle Modifier) for Ford.

- The Transportation Development Centre (Transport Canada) has supported development of cylinders for compressed natural gas vehicles, and this has seen Powertech Labs of B.C. become a world authority on cylinders for compressed natural gas storage.

- CANMET supported the development of a new concept refuse/recycle collection vehicle using natural gas-powered hybrid hydrostatic drive system. This vehicle is now in regular service, and a successful part of the Markham's Model Community Collection Program.

- CANMET supported Alan International Limited in the development of a new lightweight aluminum alloy compressed natural gas storage cylinder. The first 100 cylinders were fabricated from billets cast at Alan Extrusions, Pickering. These cylinders are being used for verification testing to IBO and NEV-2 standards and for evaluation by the major automakers.

The ATF research has also produced several indirect benefits. The increased penetration of ATFs will help reduced environmental emissions. As well, the agriculture and forestry sectors will benefit from the production of ethanol from biomass, including waste material. Advanced materials, such as the ceramic material developed for the LiAl/FeS batteries, have applications in other sectors.

The development of the fuel cells will have application in power generation, particularly for small operations and uninterrupted power supply needs. Fuel cells give utilities flexibility in power generation as they can be off-grid or located closer to the load than conventional powerplants.

Engineering and consulting services will continue to benefit as developing countries initiate alternative fuels and efficiency programs. Canadian consultants have already provided services in this area in countries such as Malaysia, Hungary, Russia, Slovakia, China, Mexico and the United States.

Nature of S&T Opportunities and Strategies

Opportunities

The potential for growth in this industry is dependent upon a variety of factors, including government policies, emission standards and increased reliability. The export market will grow considerably because of aggressive alternative fuels policies in the United States and other countries. By the year 2000, the ATF industry is expected to quadruple. A large portion of the increase will be in the export market. It has been estimated that the market for Zero Emissions Vehicles (fuel cells, batteries, etc.) and Ultra Low Emissions Vehicles in North America, could have annual sales of $1 billion by the year 2000.

Propane and natural gas vehicles have the potential as Ultra Low Emisssions Vehicles in the next few years. They will be in demand in the United States where targets have been established for Ultra Low Emisssions Vehicles. The opportunity for Canada will be in supplying original equipment manufacturers (OEMs) with ATF components such as high-tech cylinders, electronic fuel injection equipment and infrastructure equipment.

Another opportunity will lie with the United States Clean Car initiative. Canada's opportunity lies in being able to respond to the original equipment manufacturers' needs for new materials and power systems over the next 3-6 years. Hybrid vehicles will start to emerge in this time frame. Also appearing will be innovative systems using flywheels, steady state natural gas engines and/or turbo alternators, high efficiency charging systems and advanced batteries.

Carbon dioxide stabilization goals can only be achieved through continued development and use of efficiency and alternative fuels technologies. Beyond 2000, maintaining and/or reducing greenhouse gas emissions will require greater substitution of alternative fuels for conventional crude based fuels. There is only so much that can be attained with efficiency technologies without changing the fuel.

In the period beyond the year 2000, the opportunity will exist to develop sustainable transportation energy systems (e.g., low cost ethanol production from cellulosic material). The focus will be on zero emission vehicles which rely on fuel cells, hydrogen and electric vehicle technologies where the primary energy is produced from renewable sources.

Developing these sustainable transportation technologies will lead to new industries. The growing concern with global warming and air pollution worldwide will create related markets. The opportunities for Canadian technology developers will be considerable. The challenge will be to continue to support industries such as Electrolyser to enable them to maintain their competitive advantage.

The major benefit will be to maintain a competitive position for Canada's automotive parts industry. The United States Clean Car program is a combination of the United States government and the U.S. Council for Automotive Research. This is critical to the next generation of efficient, clean, high technology automobiles. Working on our strengths, we will continue and enhance our efforts in developing advanced materials and processes, flywheel and hybrid systems. Entry to this industry will be most effective through the U.S. Council for Automotive Research and through the Canadian equivalent, CANCAR, a consortium of the "Big Three" (GM, Ford and Chrysler), coordinated by the Canadian Motor Vehicle Manufacturers Association, with the federal government as yet in a peripheral role. The U.S. and Canadian initiatives are coordinated. Thus, the Canadian industry will be well positioned to play a key role in supplying parts to the OEMs.

Alternative Transportation Fuels Profile

With the United States mandating Zero Emissions Vehicles and Ultra Low Emissions Vehicles in California, and with other states and countries no doubt soon to follow, there will be considerable opportunities for Canadian companies to supply components to this market as well as to our own domestic market. It is estimated that the demand for natural gas cylinders for natural gas vehicles in California by 2000 will exceed 2,000,000 and these will have to be light weight and inexpensive. Companies such as EDO, Dynatech, and Alan are, with NRCan support, developing cylinders that will meet this need. Other companies such as GFI, Sherex and Fuelmaker will also be in a position to exploit this market with niche products.

At present, Chrysler and GM produce some or all of their ATFs in Canada. As the United States market expands so will the demand for original equipment manufacturer ATF vehicles . This could result in increased production of these vehicles in Canada. Our S&T program, however, must continue to support the Canadian "Big Three" and their suppliers to ensure that Canadian industry remains in the forefront.

Hydrogen fuel cells and electric vehicles are the only technologies that could meet Zero Emission Vehicle standards. Ballard is a world leader in proton exchange membrane fuel cells and could be well positioned to supply fuel cells to the United States and world market. When the electric vehicle market starts to take hold there will be a need for advanced materials for batteries. INCO is developing nickel anodes for such batteries. Quebec Hydro, with 3M in the United States, is working on a lithium polymer battery and NRCan is supporting the development of LiAl/FeS batteries.

As stated earlier, the greenhouse gas and air quality issues cannot be addressed solely by improving efficiency. We must look to alternative fuel as well if we are going to have true sustainability.

Fuel cells and battery developments will spill over into other areas that require clean power. This will also apply to ATF engines for use in stationary applications. On the material side, any new alloys or processes will have many applications in many sectors. Furthermore some production techniques being developed for quality control and safety reasons will also have spillover possibilities in other industries.

S&T Capabilities

The key to this program area will be the federal government's ability to coordinate efforts through consortia of industry, other governments, research institutions, university and government laboratories. This coordination will ensure that a critical mass of resources is brought together to advance the technologies. NRCan has the appropriate expertise in the transportation field to facilitate and promote the development of the necessary strategies. The national nature of transportation also requires strong central leadership that the federal government can bring to the table.

CANMET materials laboratories and expertise will be valuable in developing advanced materials and processes. The Energy Diversification Research Laboratory and the Energy Research Laboratories will provide expertise and assistance with the development and evaluation of biodiesel, vehicle catalytic converters for emissions control, battery electrodes and cells, and fuel cells.

Transport Canada and Environment Canada have testing capability and the expertise to facilitate safety related R&D, emissions evaluations and cold climate performance evaluations.

As many of the individual industries are SMEs, without large and sophisticated R&D facilities, government and provincial laboratories can become the R&D arm of these industries. This has proved valuable in the past and will continue to be necessary. For example, the National Research Council supports fundamental studies, including combustion characteristics of ATFs and the chemistry of ozone formation in the lower atmosphere.

Nature and Feasibility of Federal S&T Strategies

Strategies and Action Plans

The major strategy to realize these opportunities will be to work in those areas where Canada has world leadership. These areas include: EDO, Alcan and Dynatech in natural gas vehicle cylinders, FES in flywheels, and Fuelmaker in small compressors. Concentrating on unique key technologies rather than trying to develop complete vehicles and or systems will be more cost effective.

The strategy will continue to focus on partnerships and consortia with industry. The government role in the development of standards and regulations will remain important in creating the environment for the introduction of new technologies. Infrastructure development will require the government to play a larger role. By the year 2000, financial support will shift from near term technologies, such as propane and natural gas, to hybrids, flywheels, hydrogen and fuel cells.

The government must be partners with the Big Three automobile manufacturers and look toward supporting technology development under CANCAR (the government-manufacturers consortium) to enhance the automobile parts manufacturing industry. Again the focus must be in those areas where we have the expertise and capabilities.

Federal R&D actions will emphasize the following, compatible with the analysis on characteristics on innovation in the sector:

- lowering the costs of ATFs and ATF components - areas of interest include onboard storage, cold weather performance, fuelling systems, high energy and power density batteries, membranes for fuel cells and hydrogen production, onboard reforming of a hydrogen carrier;
- flywheels and hybrid vehicle systems;
- advanced material and processes to enable lighter weight material to be used in automobiles;
- enhancing the emissions benefits of ATF with a focus on Zero Emissions Vehicle technologies - areas of interest include ground level ozone-forming emissions, unburnt methane release, carbon dioxide and nitrogen oxides emissions;
- reducing risks to safety; and
- positioning Canadian industry for the growth of Ultra Low Emissions Vehicles and Zero Emissions Vehicles - the export market offers many opportunities.

Canada has become a world leader in the technologies required to realize the opportunities identified previously. Thus, there is a critical mass of expertise and facilities in both the private and public sector. There is a need to increase the knowledge in the ATF area. This will be developed through laboratory and industry participation. The key will be the commitment of resources by governments to fulfil the needs of the program. Not just short term commitment but longer term funding stability is important.

Other Considerations

Impact on Sustainable Development and Environmental Considerations

Increased use of ATFs will take us in the direction of a transportation system that is compatible with the principle of sustainable development. However, any such move will be preceded by a transition period of twenty years or more as the transportation field moves from its present petroleum-based position to a sustainable energy, zero emission position. There will be a series of steps that will include continued improvements in fuel efficiency, substitution for gasoline and diesel with more environmentally friendly fuels and eventually the sustainable energy source or carrier.

Regional Development

Transportation is a national concern and benefits will accrue to all regions. Some regions will only benefit from reduced transportation costs, however, these are major items in the transportation of goods and people. A sustainable transportation energy system would be such that some of its energy would be local, coming from regions other than the present oil-producing provinces. Renewable sources of electricity, hydrogen, ethanol, and methanol will have the potential to be produced in the local market area.

There will be a shift in manufacturing of components, parts and systems from Ontario to other provinces. B.C. will be a centre for the production of fuel cells. Alberta is developing a capacity to produce natural gas vehicle cylinders and other provinces could become involved in the production of other components. On the advanced material applications to automotive parts, central Canada will continue to lead in production.

International Aspects

Transportation is global. Greenhouse and air quality issues are global. Added to the fact that many countries are evaluating methods to use sustainable, indigenous resources, there is great scope for international cooperation, networking, agreements and standards. In many cases this sector has established the appropriate international networks and agreements. The IEA provides a major mechanism for international cooperation.

The International Standards Organization will play a critical role in ensuring that standards are developed that protect public health and safety, and at the same time do not restrict trade. In fact, international standards will be essential to the growth of the alternative fuel industry by ensuring that technical barriers are not created. Standards will permit economies of scale in the initial stages of growth when local markets are small.

There is already a multidirectional flow of knowledge in this sector through numerous conferences, international associations and technology transfer programs. In several areas, Canada will be the source of this knowledge.

Indicators of S&T Impacts and Success

The key indicator will be the increased growth both in the existing alternative fuels industry and the creation of new industries. Export sales of fuel cells and other items will be another major indicator. This will also translate into increased employment in the field.

Another key indicator will be the maintenance of, or the increase in, the share of the North American automobile parts market by Canadian companies. Increased use of Canadian technologies, such as natural gas vehicle cylinders, GFI fuel injection systems, INCO nickel anodes, in the original equipment manufacturers' production of vehicles and advanced batteries. Increased private sector spending on R&D will also show success in this field.

Alternative Transportation Fuels Profile

Synopsis: Alternative Transportation Fuels

Importance for Wealth and Job Creation

- ATFs, with lower greenhouse gas emissions, support sustainable development.

- The technologies are maturing as shown by the shift from conversions to original equipment manufacturing, with the attendant lower costs and production stability.
- The alternative transportation fuels and efficiency industry contributes $600 million to GNP and 2,500 jobs.

- There are about 150,000 propane and 26,000 natural gas vehicles operating in Canada supported by 5,000 propane and 200 natural gas stations.

- Exports of technology are estimated at $15-20 million per year.

Future S&T Strategy

- Sustain the current federal investments in S&T for ATFs.

- Centre the strategy around the objectives of:
  - lowering costs;
  - enhancing the emission advantages;
  - identifying and reducing the risks to health and safety; and
  - position the industry for growth in Ultra Low Emissions Vehicles and Zero Emissions Vehicles.

- Emphasize areas where Canada has an advantage; this will include support for:
  - concentrating on unique key technologies rather than on complete vehicles or systems;
  - supporting technologies for ATF infrastructure; and
  - supporting ATF component technologies that lead to the use of Canadian resources such as nickel for high energy density batteries and aluminium for lightweight gas storage cylinders.

- Coordinate federal S&T activities through PERD, and integrated with industry and provincial research networks and consortia.

- An industrial development strategy for alternative transportation fuels and supporting technologies is required to further focus the S&T investment and seize the narrowing window of opportunity for Canadian companies to become suppliers to growing continental and international market. There is already evidence that, in the absence of such a strategy, Canadian companies are considering relocation to the U.S.A.

Oil, Gas, and Petroleum Products Sector Profile

Sector Overview

Introduction

The oil and gas industry is divided into two major sectors: the upstream producing sector, and the downstream refining and marketing sector. The upstream sector includes more than 500 exploration and production companies plus hundreds of associated businesses; such as, seismic and drilling contractors, service rig operators, engineering firms, and various scientific, technical service and supply companies. The downstream sector includes pipeline systems, refineries, gas distribution utilities, oil product wholesalers, service stations and the petrochemical manufacturing industry.

Most of Canada's oil and gas production currently comes from the Western Canada Sedimentary Basin. This geological area covers most of Alberta, and parts of British Columbia, Saskatchewan, Manitoba, the Northwest Territories, and the Yukon. Approximately 16% of Canada's oil supply is currently produced from oil sands surface mining projects in Alberta. The bitumen is separated from the sand and undergoes primary upgrading to synthetic crude oil. Bitumen and heavy oil are also processed into synthetic crude oil at two upgraders in Saskatchewan. These two upgraders account for another 6% of Canadian oil production. Frontier projects such as Cohasset-Panuke (off the coast of Nova Scotia), Bent Horn (in the Arctic Islands), and Norman Wells (in the Northwest Territories) currently represent about 4% of Canada's oil production.

Gas plants in Western Canada process natural gas to meet pipeline specifications. Water vapour, carbon dioxide, and other impurities are removed. Hydrogen sulphide is removed from "sour" gas and then further processed to yield elemental sulphur. Natural gas liquids are also extracted to provide fuels such as propane, or petrochemical feedstocks such as ethane.

The industry also includes major pipeline systems for transporting crude oil, finished products, and natural gas throughout Canada and into the United States. There are two major Canadian crude oil pipeline systems: the Trans Mountain Pipe Line Ltd. (TMPL) starts at Edmonton and delivers crude oil, semi-refined and refined products 1,250 km to the Vancouver area. The larger Interprovincial Pipe Line Inc. (IPL) system consists of three major sections stretching 3,700 km from Edmonton to Montreal. Both TMPL and IPL are planning expansions. As for natural gas, there are about 320,000 km of gas pipelines. Of this, about 11% is for collecting gas in production areas, 19% for transmission, and 70% for distribution.

The pipeline systems are complex arrays extending over a variety of terrain, and often covering great distances. They consist of pipes, valves, compressors and pumps, metering and control systems, and inspection equipment. Opportunities for new technologies exist throughout these systems and at all stages, from design through construction and operation to inspection and leak detection.

Other important sectors of the industry are the refining and petrochemical manufacturing sectors. Both industries are technologically sophisticated and important components of Canada's industrial manufacturing base. There are twenty-four refineries in Canada operated by twelve companies. Two of the major refining centres are located in Edmonton and Sarnia. The current Canadian refining capacity is 284,000 m^3/d, down from 370,000 m^3/d in 1979. This reduction in capacity has been associated with the closure or downsizing of fifteen refineries and the upgrading of two others. Furthermore, Canadian refineries have improved their processing equipment since the mid-1970s to increase their production of light products such as gasoline, diesel, and jet fuels. This rationalization should reduce costs and increase efficiency, thereby improving the competitiveness of the remaining plants. Projections indicate a gradual increase in demand for refined petroleum products over the coming decades. However, refineries will be faced with changing product specifications and other environmental concerns, and increased competition from larger-scale and more efficient refineries in the United States. Canadian refineries designed to process light crude oil face gradually declining production of this feedstock in western Canada. While the upgrading of existing Canadian refineries to handle heavier feedstocks is an option, the financial burden of such an investment would be considerable.

Primary petrochemicals are divided into four groups: olefins (ethylene, propylene, butadiene, and butylene); aromatics (benzene, toluene and xylene); methanol; and ammonia. The primary petrochemical industry supports clusters of value-adding secondary industries such as agriculture, plastics, cosmetics, textiles, rubber, and forest products. Much of Canada's petrochemical production is exported to the U.S. and Asia. The diversity of the industry and its export-oriented nature means that its outlook is closely linked to world economic growth and its competitive position. In the last decade, the bulk of the growth in primary petrochemical production has been in Alberta, due in part cheaper natural gas and ethane and lower transportation costs. The industry in central Canada, which was predominantly naphtha-based, has invested heavily to increase capacity and flexibility in the mix of feedstocks that can be used. One area of opportunity for the industry is in oxygenates such as MTBE for reformulated gasolines.

In the future, Canada's oil production will be based on a combination of sources. Although their production is expected to decline, conventional oil fields in western Canada will continue to provide a significant portion of our supply for several decades. New technologies such as 3-D seismic and horizontal wells are helping the industry to find smaller reservoirs and to increase production per well. Advances in enhanced oil recovery techniques will also help the industry extract more of the 70% of oil in existing reservoirs that cannot be recovered by conventional production methods.

A second source will be the oil sands, one of the world's largest petroleum resources. New S&T will play a key role in deciding the timing and extent of the development of our oil sands resources. Bitumen and synthetic crude oil could possibly account for as much as 50% of Canada's oil production by the year 2010.

A third source is the frontiers. The Hibernia project will produce about 125,000 barrels per day when it comes on-stream. Another large offshore project for the Terra Nova field is expected to follow. Major oil reserves have also been found in the Beaufort Sea-Mackenzie Delta area, but developments there require either higher world prices or advances in S&T to lower costs.

Future supplies of natural gas are expected to first come from gas-prone areas of Alberta and northeastern British Columbia, and the southern parts of the Yukon and the Northwest Territories. Natural gas has also been discovered in the Mackenzie Delta/Beaufort Sea region, the Arctic Islands, and off the coasts of Newfoundland and Nova Scotia. Offshore Nova Scotia gas may be the first frontier gas to be developed, followed by Mackenzie Delta gas.

Key Dynamics of the Industry

Petroleum is the lifeblood of the Canadian economy. Nearly all of Canada's surface, sea, and air transportation systems are dependent upon petroleum-derived fuels. Oil and gas are also the primary sources of heat for residences, and commercial and industrial buildings. Oil and gas liquids account for 37% of Canada's energy consumption. Natural gas provides another 28%. Petroleum, natural gas, and natural gas liquids are the feedstocks for manufacture of lubricants, octane boosters, synthetic fibres, plastics, fertilizers, and pharmaceutical intermediates.

The petroleum industry is a major business sector of the Canadian economy. In 1992, the upstream industry provided direct employment for 61,000 Canadians and estimated indirect employment of 53,700. Downstream sector employment figures were 148,300 direct and 72,400 indirect. The industry's capital expenditures in 1993 exceeded $9 billion, or 7% of total Canadian investment. Petroleum-related expenditures on offshore frontier lands were $1.03 billion in 1993 and accounted for 4,958 person years of employment. In 1993, upstream industry revenues totalled to $21.2 billion; 53% from the sale of crude oil, 34% from natural gas, and the remaining 13% from natural gas liquids and sulphur. The extensive network of oil and gas pipelines added almost $5 billion to Canada's GDP in 1993. Capital investment in the pipelines sector approached $2.2 billion, over 90% of which went towards expanding natural gas pipeline capacity, mainly for the export market. Downstream net production sales were approximately $24 billion, 40% of which was accounted for by gasoline. The Canadian refining industry's contribution to the GDP was around $3.7 billion in 1993. Investment in 1993 was less than $500 million. Exports of refined petroleum products in 1993 are estimated to be $2.7 billion, about $550 million more than the equivalent amount of crude oil. Refined product imports were valued at $1.7 billion. Canadian petrochemical producers had sales in 1992 of approximately $5.8 billion.

The petroleum industry's purchases, business transactions and sales affect every aspect of the economy. Approximately two-thirds of petroleum production sales are made to other businesses such as manufacturing, trucking, railways, and airlines. The industry is a major purchaser of steel, vehicles, construction equipment and other goods and services from the entire spectrum of business across Canada. Canadian petroleum expertise, and related goods and services are also exported abroad. Even small and medium size engineering and consulting firms have had considerable success in marketing their expertise abroad.

By the year 2000, the contribution of the petroleum industry to GNP should increase significantly in absolute terms, due to a combination of the following factors. Crude oil production is expected to be stable until the year 2000. Anticipated declines in conventional production from western Canada will be offset by increased synthetic production from the oil sands and from offshore east coast production - Hibernia in 1997 and Terra Nova a year or two later. Canada's marketable production of natural gas is expected to increase by 18% between 1993 and 2000. Canadian natural gas liquids (NGLs) production will increase in step with natural gas production. Petroleum prices are expected to rise significantly in real terms by 2000. These real price increases, coupled with the growth in production of natural gas and NGLs, will result in large increases in revenue and activity in the petroleum industry. The increase in production levels will require increased investment to expand both the production capacity and the pipeline and distribution systems. Compliance with stricter environmental standards will also demand increased investment by all of the sectors of the petroleum industry.

The petroleum industry is an important source of revenue for all levels of government in Canada. More than 20% (i.e., >$4.2 billion) of upstream revenues go directly to municipal, federal and provincial governments. These revenues are in taxes, royalties, rentals, and payments to acquire exploration rights. Federal and provincial consumption taxes account for approximately 40% of downstream sales (about $10 billion annually).

Oil, Gas, and Petroleum Products Sector Profile

Canada is fortunate to possess large reserves of petroleum and natural gas, which enables us to export our surplus production. In 1993, Canada benefited from a much-needed positive balance of trade of $10.23 billion in crude oils, refined products, gas liquids, and natural gas. This positive contribution helps offset outflows of money in other sectors of the Canadian economy.

Despite this positive trade balance, light crude production has been falling short of domestic requirements by about 20,000 m^3/d, with most of the imports coming from the North Sea. Under the current world price of $17 U.S. per barrel and a Canadian dollar worth 72 cents U.S., this represents an outflow of wealth from Canada of roughly $1.1 billion per year. Furthermore, supplies of light crude are expected to fall to about 50% of their present level by 2020. While this decline will be somewhat offset by increases in production from the oil sands and the frontier regions, Canada is expected to become a net importer of crude oil by 2009; i.e., imports of light crude oil will exceed exports of heavy and light crudes. The impact of this on Canada's trade balance is obvious. Yet this scenario need not necessarily happen. Canada has abundant petroleum resources. Technological advances from investments in S&T could enhance the economics of the development of Canada's petroleum resources and generate wealth in Canada.

Future Wealth Creation

Canada is the 3rd largest natural gas producer and the 12th largest crude oil producer in the world. Canadians also sell petroleum-related goods and services around the world and are significant participants in the international petroleum industry. Canadians have made many contributions to S&T developments in the petroleum industry and are among the world leaders in high-tech exploration methods; cold-climate and offshore operations; finding, producing and processing sour gas; enhanced recovery from conventional oilfields; producing and upgrading heavy oil; mining and processing oil sands bitumen; pipeline construction and operation; specialized controls and computer applications; environmental protection and safety training; and refining products that deliver high performance while minimizing emissions.

Canadians are currently selling exploration and well servicing skills in the Former Soviet Union, pipeline expertise in South America, and geophysical consulting in China. Canadian expertise has found an increasing market abroad, as other countries try to match Canada's high standards of efficiency and environmental protection. The legal, accounting, banking, and investment communities also apply Canadian development skills in the international petroleum business. Canadian regulatory authorities are often consulted by foreign jurisdictions as they develop legislation, technical skills, and policies for their petroleum industries. The current market for oil and gas related exports of goods and services is $6.8 billion.

Canada's vast petroleum and natural gas resources offer tremendous opportunities for wealth creation. Even at currently low world prices, these reserves are worth hundreds of billions of dollars. At current prices, Canada's remaining "established reserves" of conventional crude oil are valued at roughly $185 billion. "Undiscovered conventional crude" is valued at $640 billion. "Other discovered resources", mostly as bitumen deposits in western Canada, but also including several conventional crude discoveries in frontier regions, are valued at roughly $7.2 trillion. Even if just a fraction of these resources are ultimately recoverable, it will still represent a significant source of wealth for the nation.

Canada's annual domestic marketable production of natural gas is expected to increase by 50% between 1992 and 2020 (to 170 Bcm). This assumes an increase in exports from 58 Bcm to 96 Bcm per year. At $2.00/GJ, these exports of 96 Bcm would contribute roughly $7.2 billion annually to our balance of payments. At $2.00/GJ, established reserves of 2,220 Bcm would be valued at $190 billion. "Other discovered resources" of 769 Bcm would be valued at $66 billion. "Undiscovered resources" of 10,000 Bcm would be valued at $855 billion .

These resources can fuel Canada's economy and surpluses can be exported to aid our balance of payments (+$10.3 billion in 1993). Their development can provide much-needed employment and economic activity, as well as strengthening Canada's S&T base. However, their development is not certain. The oil and gas industry is a global industry and potential development projects in Canada must be perceived as attractive as any international alternatives. S&T will play key role in unlocking the wealth creation potential of Canada's hydrocarbon resources. Canada has a lot going for it in terms of stability, infrastructure, skilled human resources, and regulatory regimes. However, it is the continued, coordinated and shared investment in S&T by both government and industry that will maximize the "prize" obtainable from Canada's oil and gas reserves.

Sustainable Development Issues

While Canada's hydrocarbon resources are sufficient to last for many generations, their development must proceed in a safe, economic, and environmentally acceptable manner. S&T has a key role to play in minimizing the impacts of the environment on the recovery of hydrocarbons and on the impacts of that recovery on the environment. S&T ensures the safe development and transportation of Canada's vast hydrocarbon resources. Safety is promoted through activities such as remote sensing systems to study meteorological, oceanographic, and ice features or properties, which are important for offshore development, and electronic chart systems for the safe navigation of oil tankers. As well, health and safety is ensured through the development of codes, standards and regulations for the design and operation of oil and gas facilities.

S&T activities reduce energy development costs through the development of new extraction and processing techniques, evaluation of petroleum reservoirs, extension of pipeline lifetimes, etc. For the North, the biggest improvements would be in the design, construction, and operation of the facilities. Advances in S&T can increase the recovery of oil from reservoirs while minimizing environmental impacts. Improved extraction, processing changes, reservoir work, and horizontal drilling can be applied to reservoirs in any geographic area.

Minimizing the environmental impacts is also a key component of S&T activities in this area. S&T activities help to develop a better understanding of the environment-energy development linkages. For example, gaining a better understanding of environmental forecasting is a key for developing of offshore and frontier oil and gas resources in an environmentally acceptable manner. Other specific environmental issues include drilling and production discharges; oil sands tailings; air quality (emissions); site remediation; prevention, control, and clean-up of oil spills.

The Nature & Role of S&T in the Oil & Gas Industry

Characteristics of Innovation

The oil and gas industry is a developer, a user, and a driver of high technology development across a wide range of technologies. It has been estimated that between 5 - 25% of the capital costs of offshore oil and gas production systems will be for technology-intensive equipment and systems. It has also been estimated that 25% of the high technology content is in highly skilled labour for design and engineering. A partial list of the technologies developed or used by the oil and gas industry includes: supercomputers for 3-D seismic; geophysics; geology; permafrost engineering; geotechnical engineering; telemetry; remote sensing technologies and imaging technologies; metallurgy and advanced materials; drilling fluids chemistry, enhanced oil recovery chemicals, corrosion inhibitors; advanced separation technologies; environmental chemistry for spills and site clean-ups, including bioremediation technologies; catalysis; chemical reaction engineering; surface mining techniques and materials handling for oil sands; remotely operated vessels for undersea work; automated process control and expert systems; oceanography; ice-related technologies; meteorology; and navigation and positioning systems. There is hardly any area of S&T that is not used, developed, or driven by the demands of the oil and gas sector.

The oil and gas industry is a global industry. Nevertheless, there are many areas where the opportunities are unique to Canada (such as the oil sands), or where Canada has a clear technological lead (such as arctic exploration and development, and sour gas processing.). The financial strength of the industry is a major factor in deciding the development and adoption of new S&T. The strength of the industry is in turn affected by world oil prices and government fiscal and energy policies.

The players in the innovation system include industry; centres of excellence co-funded by industry and governments such as C-CORE, C-FER, and PRI; universities; provincial governments; and the federal government. The players can be categorized as research funders, research performers/technology developers, and S&T users. The "majors" have quick access to their companies' global R&D. Their Canadian R&D facilities generally focus on Canadian-specific issues, although Imperial Oil Ltd. does have the Exxon global mandate for lubricants R&D. Financial pressures have led to an emphasis on collaborative R&D to reduce costs and to achieve a critical mass of funding. This collaboration has produced the added benefits of better priority setting, elimination of duplication, and quicker diffusion of the resultant S&T. The downside of these financial pressures has been a reduction in the amount of R&D performed in Canada.

An example of collaboration is the Canadian Oilsands Network for Research and Development (CONRAD), which was launched in January 1994. CONRAD is an industry-led research network that fully integrates the various oil sands and heavy oil research programs of industry research laboratories, federal and provincial research organizations, and Canada's universities.

CONRAD's fourteen founding partners come from industry, universities, and provincial and federal governments. Together they spend more than $100M annually on oilsands and heavy oil R&D. CONRAD will pursue R&D in four major areas: surface mining of bitumen, in situ recovery, upgrading, and enhanced environmental performance. The collaboration ensures that all segments of the innovation chain, from basic research to commercialization, are closely linked. CONRAD replaces a competitive approach with a shared research vision that results in better use of research dollars and resources and fosters closer ties between the partners. Industry's active participation will ensure that CONRAD's commitment to improving the competitiveness of the oil sands industry through the development of superior technology is achieved.

Oil, Gas, and Petroleum Products Sector Profile

The Potential for S&T Advancement to Support Wealth Creation

S&T advancement is one of the major factors governing both the intermediate and long term potential for the creation of wealth in the Canadian oil and gas industry. Many of Canada's major petroleum reserves (e.g., oil sands, Beaufort Sea oil, and Mackenzie Delta gas) are uneconomic, or just marginally economic under current oil price scenarios and current technology. S&T can spur the development of these marginally economic reserves by lowering their capital and operating costs, while at the same time ensuring their environmentally sound development.

The oil and gas industry is a sophisticated and technically advanced industry that provides a core nucleus around which many other leading-edge technology industries (eg. biotechnology, microelectronics, environmental) can cluster and be developed. For example, many new environmental technologies owe their development to the petroleum industry. It is no coincidence that Alberta has one of the largest associations of companies involved in the newly emerging environmental industry.

S&T advances in leading-edge fields can have major impacts on industry productivity. For example, conventional tests take a minimum of five hours to find out the percentage of oil in oil sands that have been mixed with water and sodium hydroxide for processing purposes. Near-infrared spectroscopy techniques just recently developed by CANMET scientists can perform the analysis in a production setting in less than thirty seconds. This could lead to process control systems to improve the efficiency of the extraction operation. Not only would oil sands production benefit from this, but so too could Canadian electronic instrumentation manufacturers.

Whatever the world price of crude, advances in S&T will enable the Canadian oil industry to develop our petroleum resources more efficiently at a lower cost, with less impact on the environment, and with a greater degree of resource recovery and utilization. S&T advancement can also reduce the risks and enhance health and safety when operating in harsh environments such as the offshore and arctic. S&T developments by the Canadian oil and gas industry can be exported to other nations as goods and/or services.

Strategic Needs

The strategic needs of the Canadian oil and gas industry are as diverse as the industry itself. For conventional oil we need better S&T for finding remaining reservoirs and extracting as much oil as possible from them. Two recent developments, 3-D seismic and horizontal well technology, offer dramatic evidence of the impact that S&T advances can have on the industry. 3-D seismic and advanced data and imagery processing have aided the detection and better delineation of smaller reservoirs. Horizontal well technology has enabled the industry to access more of the reservoir from fewer wellheads. As a result, production and recovery rates have greatly improved. Compared to vertical wells, horizontal wells have first-year production rates three times higher and recovery per well is typically more than double. The recent rejuvenation of the oil and gas industry in Alberta and Saskatchewan is due in part to S&T advances in these two areas.

Site remediation and clean-up of abandoned wells is an environmental issue with significant economic implications for the conventional oil and gas industry in Western Canada. Contamination of soil and groundwater throughout the Western Canada Sedimentary Basin is a major concern to the industry and pubic. Potential conflicts are caused by pollution concerns affecting agriculture and cattle ranching, both major economic drivers in Canada's conventional oil and gas producing areas. Innovative technologies are required so that more cost-effective methods can be used to deal with the concerns. Greater emphasis on the <u>prevention</u> of pollution is required to reduce the end-of-pipe wastes generated by the industry. Risk assessment methods, as they relate to the clean-up and abandonment of facilities, are a major priority of industry. Advances in environmental S&T would enable the industry to carry out more thorough clean-ups at lower cost.

With respect to the oil sands, breakthrough advances in S&T are needed to minimize environmental impacts, and to lower capital and operating costs. Environmental concerns regarding the wastes generated by this industry require new technologies to manage existing tailings ponds and to reduce the size of future ponds. New, more efficient ways need to be found to extract the bitumen from the oil sands and to upgrade the bitumen to good quality synthetic crude oil. The current technologies of surface mining, hot-water separation, and carbon rejection are costly, energy- intensive methods for accessing, extracting and upgrading bitumen. Cyclic steam drive for the in-situ extraction of bitumen and heavy oil is another costly and energy-intensive process. New processes such as "Vapex", which uses horizontal wells and natural gas liquids for extraction and in-situ deasphalting offer possibilities for major reductions in costs and environmental impacts.

For East Coast offshore developments, S&T advances are needed across a broad spectrum of technologies including multiphase flow and metering, remote sensing, ice detection and management, geotechnical engineering, remotely operated vessels, telemetry, floating production systems, environmentally-benign drilling fluids, etc.

For developments in the Beaufort/Mackenzie Delta, S&T advances are required in permafrost engineering, ice-structure interaction, gas hydrates, navigation and shipping technologies, etc. The northern environment will also require S&T advances to minimize the impacts of developments.

On the downstream side, refining and petrochemical manufacturing will require advances in automated process control and expert systems. As well, advances are needed in the S&T of catalysis to produce advanced synthetic materials, pharmaceutical intermediates, and clean burning "designer fuels" for Canada's transportation system.

In terms of knowledge and skills required, the oil and gas industry ranges across the entire spectrum of scientific, engineering and management skills including: chemistry, physics, geology, biology, meteorology, oceanography, ice detection, electronics, computer-science, and chemical, petroleum, mechanical, electrical, and civil engineering.

Ability of Industry to Capture Benefits of Technology Advancements

The oil and gas industry is a global industry throughout which S&T advancements diffuse quickly. Examples of rapid technological diffusion include the industry's expertise in offshore developments, horizontal and directional drilling, 3-D seismic, and zeolite catalysts. Canadian subsidiaries of multinationals have access to their parent's S&T advances. Independents and SME's quickly gain access to S&T advances through licensing agreements or through technical services industries.

Although companies tend to carve out niches for themselves based on land holdings or expertise in some area such as offshore operations, in general, the rapid diffusion of S&T advances places most of the industry on a more-or-less equal S&T footing.

The high rate of S&T diffusion also ensures the ability of the Canadian oil and gas industry to capture the benefits of domestic S&T advancements in areas unique to Canada, such as the oil sands, or in areas where the Canadian oil and gas industry has S&T leadership (e.g., ice engineering, permafrost science, etc.). The Canadian industry has shown itself to be very quick to capture the benefits of both domestic and international S&T advances and there is no reason why this should change in the future.

Oil, Gas, and Petroleum Products Sector Profile

Assessment of Federal S&T Capabilities

Role of Federal S&T

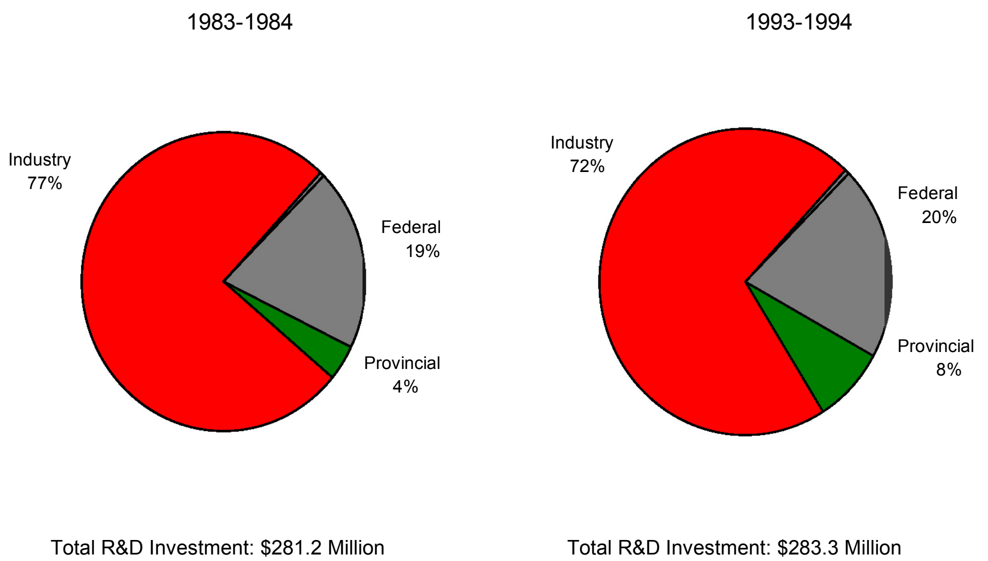
The federal government plays an active and important S&T role in the oil, gas, and petroleum products sector. Federal involvement is required for several reasons. First, hydrocarbon resources are found in many areas of Canada, including frontier areas under federal jurisdiction. These resources are of strategic importance to the entire nation. Although the prime technology strategy used in the oil and gas sector worldwide is one of adopt or adapt, Canadian resources, particularly the non-conventional ones, present some unique S&T challenges. Therefore, Canada cannot rely on an outside R&D leader to develop and license the technology that will be required to develop these resources. The degree of foreign control also limits the ability of Canadians to influence R&D decisions. Collaborative R&D enables the federal government to influence the direction of the S&T undertaken by foreign-controlled firms, and by provincial research organizations too. The structure of the industry is also a factor. Most small to medium-sized conventional oil and gas companies do little or no R&D. From the viewpoints of economy, efficiency, and critical mass, a federal S&T leadership and coordination role makes good sense. Research facilities are expensive and the number of world-class researchers in any given field is often limited. Canada simply cannot afford multiple, fragmented, uncoordinated approaches to the S&T challenges in this sector. Federal government leadership and coordination can bring together stakeholders from the energy industry, academia, and provincial governments to pool resources, avoid duplication, and share knowledge. Federal involvement also stimulates investment in higher-risk, higher-payoff R&D, and provides support for longer-term basic research. The federal government must also perform S&T activities to fulfil its regulatory and stewardship responsibilities for the environmentally sustainable development of Canada's hydrocarbon resources.

R&D Investment Trends

In 1983, the total investment in oil and gas R&D was $281.2 million (see Figure 13). The major R&D investor was industry, which invested $216.1 million. The federal government contributed $54.5 million, while the provinces provided $10.6 million. The main areas of R&D were exploration, extraction, in situ production, refining and transportation.

Figure 13

Oil and Gas R&D Investment



The federal R&D investment in this area comes from several sources: Departmental A-base activities of Natural Resources Canada, Environment Canada, and Fisheries and Oceans Canada, and from the interdepartmental Program of Energy R&D (PERD). The federal investment supports R&D activities in the area of: enhanced oil recovery, oil sands extraction and upgrading, frontier oil and gas exploration, reservoir evaluation, onshore and offshore geotechnics, structural engineering and materials, ice-structure interaction, personnel safety, environmental forecasting and design, environmental impacts, pipeline/permafrost interaction; pipeline engineering, hydrographic technologies and charting, and marine shipping. These investments ensure that Canada's oil and gas resources are developed and upgraded in a safe, economic, and environmentally acceptable manner.

By 1993, the total investment in oil and gas research had increased marginally to $283.3 million. The provinces increased their contribution to $22.7 million, an increase of 114% from 1983. The federal government's investment increased by 3.5%, bringing their contribution up to $56.5 million. Industry's contribution fell by 5.6%, to a total of $204 million.

Oil, Gas, and Petroleum Products Sector Profile

Nature and Feasibility of Federal S&T Strategy

The guiding strategy for federal S&T activities is to work in collaboration with industry and provinces on key issues where the federal government can effectively carry out its role of leadership and coordination, and where its capabilities can have the greatest impact. Federal petroleum-related S&T activities are multidisciplinary and involve many departments and agencies. The federal government has a mechanism to coordinate and focus its energy-related S&T activities through its interdepartmental Program of Energy R&D (PERD). The PERD network also helps the coordination of "A base" funded S&T activities and provides a mechanism for realigning the S&T activities of departments to deal with emerging issues.

At the more specific levels, many federal laboratories have industry advisory councils and use very efficient and effective forms of collaboration such as research consortia to stimulate the involvement of SMEs and to help the quick commercialization of resultant technologies. The federal government is a key participant in research networks and programs such as the Canadian Oil Sands Network for R&D (CONRAD) and the Groundwater and Soil Remediation Program (GASReP). Federal research organizations also organize many technical symposia and workshops on petroleum-related issues such as: pipelines, reformulated gasolines, frontier oil and gas, etc. These symposia help coordinate the research efforts of the various stakeholders and foster alliances, thereby inducing technological innovation.

The federal government has specialized laboratory facilities and the knowledge and expertise of its research scientists, engineers, and technicians in a wide variety of scientific fields. These federal S&T capabilities help fill the gaps in industry and provincial governments. They also enable the federal government to fulfil its leadership and coordination role for the development of Canada's hydrocarbon resources. These federal facilities and expertise are strategic national assets, available to work in collaboration with Canadian SMEs that lack the critical mass of researchers and equipment necessary to achieve S&T advancements. Federal facilities and expertise also give SMEs and Canadian consultants credibility and backup when they bid on international projects. They fill an important void in an industry sector characterized by a high degree of foreign control, and many SMEs with limited or nonexistent R&D capability. If it were not for some federal facilities, certain critical S&T capabilities simply would not exist in Canada because of the structure of the industry.

All stakeholders - the federal government, provincial governments, multinationals, and

SMEs - must work together if Canada is to realize the full potential of the opportunities offered by its hydrocarbon resources. No one party can do it alone. However, to have the required knowledge and credibility to carry out its leadership role, or even to exert any influence, the federal government must have sufficient S&T capability and expert knowledge in the form of laboratory facilities and first-class researchers. Compared to direct intervention, federal S&T capability represents a much more cost-effective way of creating wealth, providing knowledgeable leadership, and influencing the direction taken by industry and the provinces.

Budget cutbacks have steadily reduced the federal petroleum-related S&T capability over the past decade to critically low levels. At the same time, financial difficulties have also forced the industry and provincial governments to drastically reduce their research capabilities. This combined reduction in Canadian S&T capability in a strategic, wealth-generating sector is a serious concern. If Canada loses its S&T capability in key areas such as the oil sands or the frontiers, that capability could be regained only with great difficulty and at great cost. Canada's population and economy are growing and all projections show that Canada will consume more petroleum in the future. S&T advances will be a decisive factor in determining whether that petroleum comes from Canadian resources, with the resultant economic activity and benefits accruing to Canada, or whether it will be imported from foreign sources with a resultant outflow of Canadian wealth.

Profile/Impact of Current Activities

The principal federal government participants in S&T related to the oil, gas and petroleum products sector are: Natural Resources Canada (NRCan) - CANMET and the Geological Survey of Canada (GSC); Environment Canada; National Research Council (NRC); Transport Canada; National Energy Board (NEB); Fisheries and Oceans (DFO); and Indian and Northern Affairs Canada (INAC). CANMET concentrates mainly on oil sands, heavy oil, conventional oil and gas, and pipelines. GSC applies its geoscience expertise to geotechnical issues in the frontiers and the Western Canada Sedimentary Basin (WCSB). As expected, Environment Canada is involved in all sub-sectors. Significant environmental work is also performed by CANMET, NEB, and DFO. Transport Canada, DFO, NEB, INAC, and NRC work primarily on frontier oil and gas.

The oil, gas, and petroleum products sector is very broad and diverse and cannot be treated as a homogeneous entity. In this paper, it is broken down into the following sub-sectors for descriptive purposes: oil sands and heavy oil, conventional oil and gas (including refining and petrochemicals), frontier oil and gas, and pipelines.

Oil, Gas, and Petroleum Products Sector Profile

Oil Sands & Heavy Oil

Federal government S&T on oil sands and heavy oil focuses on developing new and improved technologies to help industry in developing Canada's extensive oil sands and heavy oil resources in an economic and environmentally sustainable manner. It is concentrated in key niche areas where federal S&T capability can lever the most resources and make the largest impact. The federal research is divided into three programs: Production/Extraction, Upgrading, and Environment. The work is coordinated with industry, provinces, and universities through CONRAD.

The federal production/extraction R&D includes an enhanced oil recovery (EOR) cost-shared program for the in situ recovery of bitumen and heavy oil as well as in-house federal laboratory R&D programs. The in-house R&D programs deal with bitumen transportation, separation efficiencies, and the quality of the extracted bitumen.

The federal upgrading R&D involves primary and secondary upgrading to produce pipelinable crude, synthetic crude oil (SCO), and light transportation fuels. The research has three primary thrusts: incremental R&D to improve conventional upgrading, exploratory R&D for breakthrough technologies with potential for large capital cost reduction to induce new developments, and fundamental research that provides understanding and direction for the preceding two thrusts. The program focuses on areas that the industry has identified as having potentially high impact/payoff, such as emulsion upgrading, use of alternate sources of hydrogen, and product quality improvement.

By increasing upgrading/refining capacity in Canada, producers could improve access to processing capacity for their bitumen and heavy oil. About 80% of Canadian heavy oil production is exported raw to the U.S. for further upgrading. About 65% of the bitumen produced in Canada is upgraded to synthetic crude oil in Canada.

In 1993 the Federal and Alberta Governments announced the creation of the National Centre for Upgrading Technology (NCUT) at Devon. This joint venture is managed by CANMET and staffed by CANMET's Western Research Centre (WRC) and the Alberta Research Council. All of CANMET's bitumen and heavy oil upgrading research is delivered through NCUT. NCUT will use CONRAD to facilitate transfer of upgrading technologies to industry and to provide guidance regarding the commercial relevance of its research. CANMET and Syncrude recently formed a strategic alliance in which Syncrude's major upgrading piloting work is done by NCUT. This alliance will be used as a model for similar piloting services for other upgraders.

The environmental research effort focuses on the fine tailings produced from conventional mined oil sands plants, the separation of oil from effluent streams, cost-effective methods to treat and dispose of heavy oil sludges and wastes, and treatment and recycling of produced water from surface and in situ applications. The tailings program is aimed at providing a fundamental understanding of the formation and stability of the fine tailings so that long-term disposal solutions may be applied. The produced water program is largely focused on the transfer of novel technologies from related applications both from Canada and abroad. Federal participants include CANMET, Environment Canada, and the NRC. Several oil companies and the Alberta government also participate in these collaborative efforts. Research has also examined the effects of the oil sands industry on surface and groundwater with recommendations addressing potential concerns of existing and planning new facilitates.

For oil sands and heavy oil S&T, the primary clients include the major stakeholders, i.e.: Syncrude, Suncor, Imperial, Shell, Canadian Occidental, Husky, Saskoil, and AOSTRA. Future developments in oil sands and heavy oil will include smaller operators producing bitumen from small in situ or satellite surface mines that will feed local or regional upgraders. Thus, the oil sands industry will become more like the conventional oil industry with many small independent producers. Small producers lack in-house research capabilities and rely on government facilities such as CANMET, the Wastewater Technology Centre of Environment Canada, and the NRC to meet their research needs. The federal government, in its laboratory facilities and in the expertise of its scientists and engineers, offers some unique capabilities in the critical areas of surface science, separations technology, and upgrading. These capabilities, when integrated with complementary capabilities of industry and provincial research organizations, will give Canada its best chance to develop the technologies needed to develop our extensive oil sands and heavy oil resources.

It is difficult to accurately predict the potential benefits of future S&T advances. Perhaps the best indicators are past successes. For example, through continuous optimization and technology enhancement, Syncrude Ltd. has managed to reduce operating costs to about C$15.40/bbl - 37% below 1982 levels. An example of the direct benefits in the heavy oil area is provided by the success of the Tangleflags North New Horizontal Well Technology/Steam Flood Process. This new technology has increased the oil recovery tenfold to 1.3 million BOE. CANMET's work contributed to the optimization of oil production and towards the choice of locations for future investments in horizontal wells. This project has resulted in gross sales to date of $37 million of oil and anticipated sales of $150 million over the next fifteen years. Since this project, 1,100 other oil fields in Saskatchewan and Alberta have made use of horizontal well drilling technology. Saskatchewan Energy and Mines estimate that 800 jobs have been created so far and that

300 jobs per year will be added in Saskatchewan alone because of horizontal well applications.

Federal S&T also supports Canadian SMEs in their international trade efforts. One example is CANMET's recent technical assistance to Zeton Inc., which helped this SME from Ontario win a major overseas contract for its microactivity test unit, used in upgrading. Sales attributable to this project amount to $500,000 - all exports. According to Zeton's president, CANMET's support and credibility as a federal government organization were significant factors in his company's obtaining the contract in Asia.

An example of a spillover benefit resulting from the application of chemical engineering expertise is the oil from sewage sludge process, developed at Environment Canada's Wastewater Technology Centre (WTC) in Burlington, Ontario. The conversion of sewage sludge to valuable fuel oil offers both environmental and energy benefits. The technology has been licensed to SNC Lavalin to commercialize. International sales are anticipated in the U.S.A., Europe, and Asia.

An example of a spillover benefit in the area of instrumentation and process control is the gamma ray detection technique, initially developed by CANMET and AECL's laboratories. This system is used as part of the control system in hydrocracking reactors. The technology has been licensed to Petro-Canada for commercial development. Sales are expected in the Middle East, in Mexico, and in South America. The gamma ray detection technology can also be applied in the production of oil liquids from pitch and coal, and in 3-phase fluidized bed reactors. In terms of capital and operating costs, this new technology is estimated to be 10% to 15% cheaper than other available techniques.

Conventional Oil

Federal S&T activities in the area of conventional oil are focused on enhanced recovery and environmental S&T. The current recovery rate for oil in place is about 30%. At this rate, current recovery techniques will leave about 40 billion barrels of oil in the ground. The location of this oil is known and the infrastructure is in place to recover it. The development of more efficient enhanced recovery technologies will increase recovery rates and extend known conventional oil reserves. The federal government plays a coordination role through a small enhanced oil recovery cost-shared program.

As the major producers downsize and rationalize their operations, they often dispose of their mature, less productive wells by selling them to smaller operators who can operate them more efficiently. The proportion of production attributed to smaller operators is increasing. These smaller operators have no R&D capabilities and must rely on external organizations such as government laboratories to help them when problems arise. For example, the Geological Survery of Canada's Institute of Sedimentary and Petroleum Geology houses the only well-equiped petroleum geochemistry facility in Canada. Canadian SMEs do not have access to this type of analytical and interpretive expertise in their own organizations, or via Canadian based service companies. In general, Canadian SMEs do not have land holdings or interests that would motivate them or enable them to carry out basin scale studies. Improved understanding of oil-source systems carried out on basin scale by the GSC stimulates and aids exploration activities by Canadian SMEs.

Government laboratory expertise in separation technologies is applied to environmental issues facing the conventional oil industry, particularly in treating produced water (some oil wells produce more water than oil), and in site reclamation. The industry is beginning to respond to the environmental issues surrounding the disposal of drilling wastes, decommissioning of flare pits and ecology ponds, and reclamation of abandoned sites. The number of abandoned well sites is increasing (close to 30,000) and the current liability for reclamation is estimated to be about $4.5 billion. The federal S&T activities fulfil a key responsibility for the development of environmental, health, and safety standards and regulations. Federal S&T also plays a leadership and coordination role in developing cost-effective technologies to address these high priority environmental issues. For example, a joint research initiative of Environment Canada, industry, and Alberta is examining bioremediation as a low cost, reliable method to treat large volumes of oily wastes.

Another example of federal S&T leadership and coordination is the Groundwater and Soil Remediation Program (GASReP). GASReP funds research on innovative ways to clean up groundwater and soil contaminated by petroleum hydrocarbons. Environment Canada's Burlington Environmental Technology Office manages the program on behalf of the members. Petroleum industry participants include the Canadian Association of Petroleum Producers, and the Canadian Petroleum Products Institute.

GASReP funds research in four areas of remediation technologies: in situ bioremediation of contaminated groundwater and soil; excavation and treatment of contaminated soil; volatilization of contaminants in contaminated soil and subsequent treatment of the off-gases; and pumping and treatment of contaminated groundwater. Research projects are conducted in the laboratory at bench scale, and in the field for technology development.
CANMET's Energy Research Laboratories (ERL) is working in collaboration with industry on cost-effective processes to produce higher quality, environmentally cleaner fuels. These include reformulated gasolines and diesel fuels from lower quality conventional crudes and offshore Hibernia crude. High efficiency separation processes based on membrane technology are assessed for removing deleterious components from refinery streams at lower cost. Work done with industrial partners, and other government agencies, develops quicker and more accurate analytical techniques for characterizing transportation fuels and

measuring levels of deleterious components in gasolines and diesel fuels. Anti-pollution devices are being developed to clean exhaust gases produced by the combustion of transportation fuels, thereby improving urban air quality.

Advances are also being made in the development of the commercial-scale production of diesel fuel additives (cetane boosters to improve ignition and combustion quality) from biomass-derived feedstocks. Specifically, CANMET is helping Arbokem Canada and B.C. Chemicals (both SMEs) in commercializing a cetane booster from waste tall oil. The cetane booster will enhance the ignition quality of diesel fuel and help reduce toxic emissions. The partners have said that they would not have done the research without CANMET's help and anticipate sales of up to $15 million over five years.

Another area of CANMET involvement is residue conversion and waste utilization. Hydrocarbon-based residues and wastes are generated in many parts of Canadian industry, including petroleum refining, plastics processing, and similar industrial processes. Contaminated byproducts are also frequently produced by plastics recyclers, refiners of used lubricants, processes that convert tire rubber to liquids and solids, and that generate oil from various biological sludges. These byproducts have problems related to environmental acceptability and marketability, and occasionally, present difficult disposal problems. CANMET/ERL uses its expertise in chemistry and chemical engineering to conduct research to solve these problems in support of both large industrial partners and SMEs.

Conventional Gas

Canadian natural gas production is shifting towards poorer quality gas with higher levels of hydrogen sulphide (H_2S). Most of the H_2S in western Canadian sour gas is extracted and the H_2S converted to elemental sulphur and water. The economics of sour gas processing would be greatly improved if the hydrogen from H_2S could be extracted without being converted to water. Waste gas streams at some gas plants, refineries, and upgraders with low concentrations of H_2S are simply flared. This produces sulphur dioxide (SO_2), a precursor of acid rain. The trend of increased gas production of lower quality, combined with more stringent controls on flaring, heightens the need for S&T advances to deal with H_2S.

Canadian firms are generally acknowledged as world leaders in sour gas production and processing. CANMET/WRC is filling a niche role by using its unique expertise in electrochemistry to develop electrochemical methods of dealing with H_2S. The introduction of electrochemical H_2S technology in scrubbing off-gas streams from upgrading and refining would allow the recycle of the hydrogen and eliminate the H_2S flaring which produces SO_2. The double benefit of reduced primary hydrogen production with SO_2 reduction is attractive both economically and environmentally. There are many engineering and consulting firms that service the natural gas industry. These firms are now beginning to use CANMET/WRC's expertise and special facilities in the work they undertake for industry. CANMET/WRC will also devote some of its efforts to electrochemical splitting of methane to produce hydrogen and ethane/ethylene.

CANMET/ERL performs research on the conversion of natural gas to higher-value liquid products important in the petrochemical, transportation, and energy sectors. Natural gas conversion research draws on expertise in catalysis, materials science, electrochemistry, spectroscopy, and process design. CANMET/ERL's Research Consortium on Natural Gas Conversion ensures that the industrial perspective steers the research direction and that data from economic evaluations is incorporated at the development stage. This consortium is the only significant R&D activity in natural gas conversion in Canada.

Research by Environment Canada and the Canadian Association of Petroleum Producers discovered that all sour gas processing plants in Alberta contained some level of subsurface soil and groundwater contamination. Since then, work has been underway at the Gulf Strachan Gas Plant applying innovative technologies to treat hydrocarbons and process chemicals in order to determine the best remediation methods for such facilities under cold-weather Canadian conditions. Results of the work can be applied to sites with similar contamination problems and physical characteristics. Numerous research partners have joined the program including the Energy and Environmental Research Center at the University of North Dakota.

The Geological Survey of Canada carries out work on predictive gas generation models which will be used by the federal government for energy resource assessments and by industry for exploration strategies.

Frontier Oil and Gas

Federal government S&T activities related to frontier oil and gas are multidisciplinary and are carried out by NRCan (GSC and CANMET), DFO, Environment Canada, Transport Canada, NRC, NEB, and INAC. The frontier areas of prime interest are the Grand Banks and Scotian shelf off the East Coast, and the Beaufort Sea/Mackenzie Delta region. The activities include: reservoir evaluation, onshore and offshore geotechnics, ice/structure interaction, structural engineering, materials, and safety; environmental studies including forecasting, design, and impacts from energy activities; and pipeline and marine transportation of oil and gas.

Research to reduce exploration, development, and transportation costs is undertaken in collaboration with industry to lower the economic threshold for frontier developments. Research is also conducted to remove environmental and regulatory barriers to development. Industry clients include companies such as Hibernia Management and Development Company, LASMO, PetroCanada, and Amoco Canada Ltd. Many clients for spillover R&D in areas such as remote sensing technologies are SMEs. A sizable portion of the resources are contracted out to the private sector to ensure the diffusion and commercialization of technology and know-how. Where their expertise is applicable, the participating departments work directly with industry to resolve technical problems.

Examples of applications of the research are:

- providing technical information and expertise to evaluate development and operating plans for areas such as Hibernia, Terra Nova, Cohasset-Panuke, and Scotian shelf gas fields;
- reducing energy development costs through evaluation of petroleum reservoirs, assessment of oil and gas transportation options, extension of pipeline lifetimes, and re-evaluation of engineering practices related to the offshore;
- developing a technical basis for regulations, standards and codes developed by or on behalf of the NEB, CSA, and Transport Canada;
- improving the forecasting of weather and ice hazards, and the understanding of ice-structure interactions;
- mitigating geological hazards through the better understanding of permafrost stability, gas hydrates, and detection of seismic hazards;
- developing the knowledge and technology base to mitigate the environmental impacts of development and production;
- undertaking collaborative R&D to develop for regulatory science purposes, and then transfer to the private sector, advanced technologies such as remote sensing systems to study ocean and atmospheric properties, and electronic chart systems for the safe navigation of oil tankers.

The potential for S&T advancements to enhance the economic benefits in the frontier oil and gas sector is considerable. A recent report[2] on S&T related to Canada's frontier oil and gas noted that: "Canada is a leader in the technology and science of oil and gas operation in the Arctic and ice-infested regions. In the past, the main emphasis has been on enabling safe and environmentally sound operations. The potential to use Canadian expertise to lower costs has hardly been tapped. Where the need for lower costs has been addressed, significant progress has been made." For example, the development of spray ice platforms (partly funded by PERD) halved the cost of conducting shallow-water exploration drilling in the Arctic.

[2]A Research Planning Study for Canada's Frontier Oil and Gas, Second Edition, March 1994.

Oil, Gas, and Petroleum Products Sector Profile

An example of the commercial benefits that can accrue from a seemingly non-commercial S&T activity is the NEB's development of National Standards for Marine Survival Suits. Besides assuring purchasers that all approved suits have a uniform minimum level of protection, the introduction of standards has also stimulated the survival suit market. An absence of firm rules for survival suit systems discouraged many safety-conscious competitors from entering the market where cost, rather than performance was the deciding factor for purchasers. The new standards allow companies to innovate and compete for the most efficient suit in design, cost, production, and features, while assuring performance. With the introduction of survival suit categories, companies can target their products at market segments.

For companies entering the international market, national standards are beneficial. Manufacturers in Canada, where survival suits must protect against some of the most extreme environmental conditions in the world, can emphasize that their suits have Canadian Government approval. Purchasers from countries with less severe conditions can be suitably impressed with the protective level of Canadian-made survival suits. Additional work is underway on personnel evacuation technologies from rigs and helicopters.

An example of spillover benefits into the electronics and shipping sectors is provided by Electronic Chart and Information Systems (ECDIS). ECDIS enable mariners to operate more efficiently and is a key technology in the prevention of grounding or collision of oil tankers. Canada's leading position in this technology and the necessary supporting infrastructure is a direct result of PERD supported projects undertaken by the Canadian Hydrographic Service in collaboration with Canadian companies. The Electronic Chart Precise Integrated Navigation System (ECPINS), developed by Offshore Systems International of Vancouver, is the benchmark system against which all other competing manufacturers around the world are compared. ECDIS has been shown to make shipping more cost-effective and Canada Steamship Lines (CSL) have recently purchased eleven ECPINS (with an option for twenty more) to make its Great Lakes fleet more competitive. CSL expects a payback for their $1M purchase within one year of operation. The U.S. Coast Guard has announced the purchase of sixteen ECPINS to make their buoy tendering service more efficient and less costly.

The expertise of federal scientists and engineers can be accessed by SMEs to strengthen their international competitiveness. For example, access to GSC's expertise in permafrost geophysics enhanced the capability of EBA Engineering Consultants Ltd. of Edmonton to provide complete field surveys related to pipeline route selection in permafrost terrain. This enhanced capability helped EBA when it was contracted by Amoco Eurasia Petroleum Ltd. to conduct feasibility studies for pipeline route selection across the Yamal Peninsula, Northwestern Siberia. The transfer of GSC expertise to EBA in 1992/93 was the first part of a larger initiative championed by EBA. The 1993/94 work will see EBA adapt and commercialize GSC-developed seismic techniques and equipment for use in marine permafrost environments in Canada and abroad. In the near future, as part of a billion-dollar program by Amoco and Canadian companies, EBA will carry out geotechnical work related to the development of oil and gas fields, the construction of pipelines and off-loading facilities (offshore), and the construction of residential housing units in the permafrost areas of north-west Siberiain.

Environment Canada's Ice Services program is another example of S&T activities which produce economic benefits for SMEs. This program provides support for airborne and satellite remote sensing of sea ice. Through this program, Environment Canada plays a strong role in supporting the offshore oil and gas industry and in technology transfer to build capacity and create wealth in Canadian industry. For example. one prime contractor, Intera Technologies Ltd., estimates their international sales of remote sensing services at $80 million over the five year life of their ice services contract.

Pipelines

The federal S&T work on oil and gas pipelines is undertaken for regulatory, environmental, and safety reasons, and for wealth creation purposes. The federal wealth creation role is one of leadership and coordination, and the application of its expertise in certain key areas. The regulatory S&T activities are driven by the mandate of the NEB. Beyond the public protection aspect, good regulations can also spur technology advancement and produce significant economic benefits. The federal S&T activities are carried out by CANMET's Metals Technology Laboratories (MTL), NEB, and GSC. The work can be divided into two sub-programs: pipeline engineering, and pipeline/permafrost interaction. The allocation of resources reflects an increased emphasis on the continued integrity of existing pipelines while developing the technology necessary for the exploitation of frontier resources.

In Canada, oil and gas pipelines represent an in-place investment of about $15 billion, with a replacement cost for the entire system of about $100 billion. Extensive stress-corrosion cracking (SCC) has been discovered on natural gas transmission pipelines in Canada. In several cases the SCC has resulted in catastrophic failure of the pipeline. Besides the obvious safety issue, the economic implications are huge.

The first issue is how frequently costly inspections must be performed. If the frequency is too high, money is needlessly wasted - about $1,000 per kilometre per inspection. If the frequency is too low, there will be catastrophic failures with the resultant economic and safety repercussions. The second issue is how long the pipeline can safely last before it must be replaced. It is one thing to detect SCC, but the ultimate goal is to prevent it, thereby prolonging the lifetime of the pipeline. Considering the size of the replacement costs and the time-value of money, the savings from lifetime extension can be very large. If the SCC problem can be overcome, it would extend the average pipeline lifetime by a decade.

Thirteen companies have joined a CANMET/MTL SCC research consortium established to consolidate efforts to solve the SCC problem. Specific S&T expertise and facilities, and its "honest leader" position as a government facility without private business interests enabled CANMET/MTL to assume the national leadership role. The research at CANMET/MTL includes a unique apparatus for pressure testing full-scale pipe sections with a pressure spectrum typical of Canadian natural gas pipelines. Fracture mechanics methodology for predicting pipeline residual life will be developed and strategies for mitigating the phenomenon in new pipelines will be devised with industry collaboration.

Other work includes the development of technologies that would reduce the costs associated with new northern pipelines through a better understanding of permafrost and ice scour and its effect on pipelines; the development of innovative methods to design pipelines, such as the application of limit states and reliability theory that could result in a high level of safety at reduced cost; the development of methods to confirm the integrity of existing systems and extend the life of these systems through internal inspection methodologies; the development of criteria for the evaluation and acceptability of defects and the study of various metallurgical phenomenon that affect the integrity of these systems; and the improved understanding of the safety issues associated with the use of pipelines through the development of risk analysis guidelines, slope stability and high vapour pressure dispersion methods. About 55% of Canada's natural gas reserves are located in frontier regions without pipeline services. S&T advances in the design, construction, and maintenance of the future pipelines that will transport this gas could have significant economic benefits for the nation. Federal S&T is required to establish the regulations governing the design, construction, and operation of these pipelines. It can thus play a significant leadership and coordination role in achieving wealth-creating S&T advances.

Other Considerations

International

Federal government petroleum-related S&T activities are closely connected to international activities whenever it makes sense to do so. There are a multitude of agreements, networks, and collaborative activities linking the federal government (and industry and the provinces) to the International Energy Agency, other foreign national laboratories, and to multinational companies. Canada participates in IEA Implementing Agreements, there is a Canada/U.S. MOU on energy research which provides a legal framework for collaboration on specific projects, and there are bilateral agreements with Russia. Canadian government scientists and engineers are also involved in the establishment of international standards.

Regional Development

In terms of regional development opportunities, Canada's major petroleum resources are in the west, the east, and the north. East coast developments are proceeding and will offer direct benefits to regions which need economic development. Irrespective of where the resources are located, the requirements of the industry for equipment of all sorts means that the economic benefits are spread throughout the entire Canadian economy. Requirements include: helicopters, computers, ships, vehicles, pumps, compressors, steel, machinery, instrumentation, specialized software, engineering services, etc.

Sustainable Development

Federal petroleum-related S&T has a heavy emphasis on the sustainable development of Canada's petroleum resources. Federal S&T activity is required to provide the necessary knowledge upon which demanding, yet attainable, environmental standards can be based. Collaborative research on mitigation technologies provides the federal government with the knowledge of what is technically and economically feasible. Collaborative research also lets the government guide research in desired directions, and stimulates Canadian industry (particularly SMEs) to participate in environmental S&T. This diffuses environmental technology and transfers expertise and capability to the SMEs. Federal S&T is aimed at high impact areas such as oil sands tailings ponds, produced water cleanup and recycle, flare emissions, contaminated soil and groundwater remediation, oil spills on ice-covered waters, etc. There are often concurrent wealth creation benefits from federal research done for environmental, health, and safety regulatory purposes. The development of environmental technologies to prevent and reduce effects of resource development can minimize waste, increase efficiencies in the industry, and create wealth for the nation.

Cost avoidance is also an area for federal S&T activities. These activities seek to reduce exploration and production costs through the wise use of environmental information (e.g. weather and ice forecasts, design information based on wave an ice climatology, etc.).

Federal S&T activities also include collaborative R&D with industry on methods to maximize the recovery of hydrocarbon resources at minimal cost, thereby extending and conserving Canada's valuable hydrocarbon resources.

Oil, Gas, and Petroleum Products Sector Profile

Conclusion

The oil and gas sector is a strategic component of the Canadian economy and has the potential to grow in importance over the coming decades. Opportunities for economic development and wealth creation abound throughout all areas of the industry and S&T advances will play a key role in bringing these opportunities to fruition. Besides the direct economic activity, oil and gas developments are significant drivers of industrial development and S&T advancements in many other sectors of the economy such as instrumentation, computers, steel, chemicals, machinery, etc. Federal S&T is necessary for regulatory purposes and can also play a key leadership and coordination role for wealth creation.

Oil, Gas, and Petroleum Products Sector Profile

Synopsis: Oil, Gas & Petroleum Products

Importance for Wealth and Job Creation

- Petroleum is the lifeblood of the Canadian economy. Oil & gas account for 65% of Canadian energy consumption.

- Direct employment more than 200,000; indirect employment more than 126,000.

- 1993 capital expenditures exceeded $9 billion (7% of total Canadian investment.)

- 1993 upstream revenues $21.2 billion; downstream net production sales $24 billion.

- Many spillover benefits in other industrial sectors such as instrumentation, computers, materials, etc. Benefits are spread throughout entire economy, all across Canada.

- $10.2 billion net positive contribution to Canada's balance of trade in 1993.

- Enormous potential wealth available to Canada if our hydrocarbon resources are developed. Otherwise, Canada will pay to import oil.

S&T Strategy

- Canada has a pressing need to develop its oil and gas resources.

- The challenge is to advance S&T to slow the decline in western Canada conventional crude production, and to develop oil sands and frontier oil and gas.

- Some S&T issues such as oil sands are unique to Canada. In other areas such as sour gas and the Arctic, Canada has a S&T lead.

- Federal government has a responsibility to sustain S&T for regulatory purposes, and for environmental, health, and safety standards.

- Fragmented structure and foreign control of the industry necessitate federal S&T leadership and coordination for wealth creation.

Oil, Gas, and Petroleum Products Sector Profile

- Federal S&T activities are coordinated through PERD, and integrated with industry and provincial S&T through research networks and consortia. Collaboration augments resources and prevents duplication.

- Federal S&T activities focus on key, high-leverage niche areas and are a cost-effective way for the federal government to coordinate and influence industry and provincial directions.

- Federal S&T stimulates investment in higher-risk, higher-payoff R&D, and provides support for longer-term basic research.

- Federal research facilities and expertise are strategic national assets used by SMEs who can't afford their own R&D facilities.

- The current level of federal investment in S&T in the oil, gas and petroleum products sector should, at a minimum, be maintained

Coal Sector Profile

Sector Overview

Introduction

Coal is the most abundant fossil fuel in the world. There are enough global potential reserves to last over 200 years at current production levels, and coal is by far the international fuel of choice for electricity generation. Canada has a competitive advantage over countries such as Britain and Germany, where coalfields are in mature stages of development and production costs are high. Canada's coal resources are widely distributed, have low production costs and have diverse technological characteristics that can compete in a number of domestic and international market niches. Coal has two primary end uses: as feedstock in the production of primary iron and steel, and as a main source of energy for electricity generation. Coal is of particular importance for industrial processes and cement manufacturing.

Coal plays a major role in Canada's economy in terms of energy investment, trade, income generation and employment. In 1993, about 69 million tonnes of coal were produced from 35 mines located in five provinces. The value of coal production was $1.8 billion (at the mine). The coal mining industry directly employs over 7,800 people in Canada, while total direct and indirect employment approximates 32,000. Indirect employment includes jobs based on moving coal on Canadian rail lines (20% of total volume moved by rail in Canada) and loading it for export at ports, as well as services by consulting firms and equipment suppliers and manufacturers. Electricity generation by coal contributes to its low cost and to the accrued economic activity that would not otherwise materialize in provinces where used.

NRCan forecasts that Canadian coal production will double to 135 Mt/year by 2020, primarily in the thermal coal sector. The proportion of total electrical supply generated from coal will also grow over this period. International markets for thermal coal are growing rapidly, which will provide expanding export opportunities for Canadian producers. Thermal coal exports are forecast to grow from the current level of 4 million tonnes/year to 16 million tonnes/year. Employment in the industry and related economic spinoffs will also increase in proportion to this forecast growth.

These benefits would not have occurred without the continued development of technologies for the expanded use of the resource. Today, the coal industry and its clients, mainly the utilities and the metallurgical industry, are facing new challenges. The global economy obliges them to remain competitive by continually improving the efficiency of their processes and by reducing their environmental impacts. The forecast growth in production and utilization of coal will increase the need for R&D to sustain this growth and to further decrease the environmental effects of increased coal combustion.

Key Dynamics of the Industry

Coal Supply

Approximately 59% of total Canadian production is thermal coal utilized in domestic markets, primarily for electricity generation. Domestic producers enjoy captive markets, as this coal is primarily used as feedstock for mine mouth power plants. The price of thermal coal is related primarily to production costs and is not affected by changes in world prices as are other commodities due to the high cost of transportation. The low mining costs associated with much of the production has resulted in low electricity costs for consumers and a relatively healthy domestic coal industry.

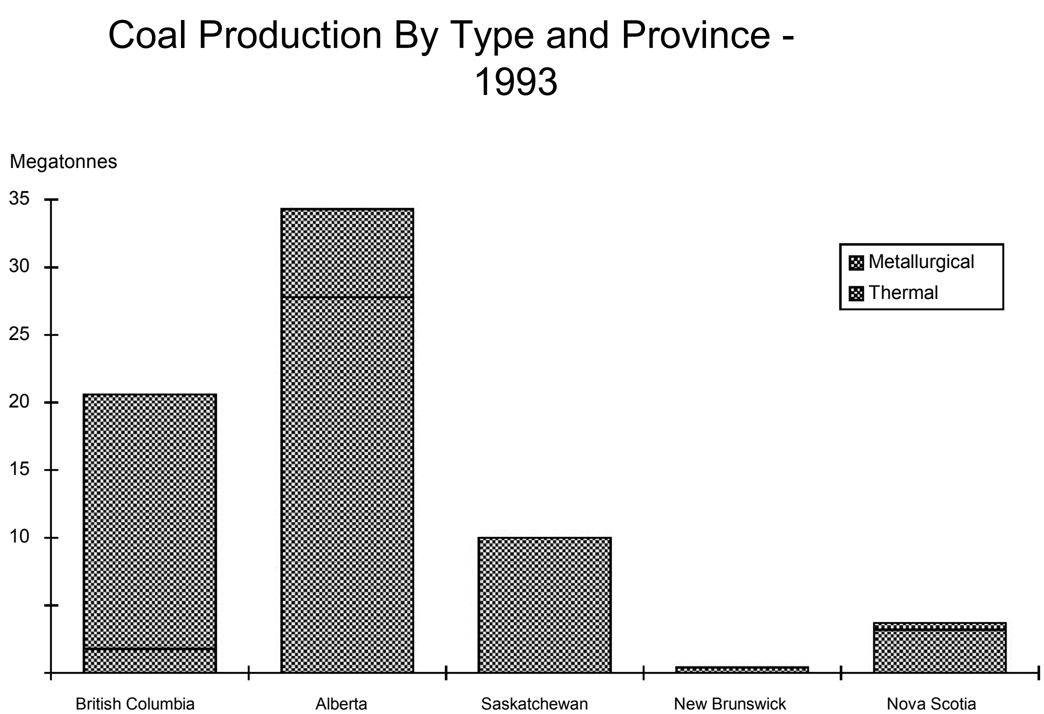
The remaining 41% of Canadian coal production is exported, primarily to the international metallurgical coal trade. In the early 1990's, Canadian producers were faced with low and falling coal prices for international sales. The over-supply of coal resulted in a loss in profitability for many exporting coal producers worldwide. In response to world market conditions, Canada's coal industry began to restructure itself to become much more efficient and competitive. The export part of the industry has made strides in its restructuring; the road to economic recovery and increased profitability is slow. While many of the larger firms are becoming profitable, many of the smaller firms are making little, if any, profit. For the most part, the export industry is still in a precarious position surviving on a cash flow basis, although it has made major strides in terms of productivity and lowering unit costs of production during the last decade. Easy improvements have been made and future ones will need refinements and technology developments.

Canada has very large potential resources of coal - some 6.5 billion tonnes of proven reserves and 39 billion tonnes of potential resources of immediate interest, or about 100 to 600 years of potential supply at current production levels. These resources represent inherent wealth domestic valued at between $65 billion and $390 billion. Coal deposits are unevenly distributed across the country. As illustrated in Figure 14, thermal coal production is mainly in Saskatchewan, Alberta, and Nova Scotia, while metallurgical coal production is mainly in British Columbia and Alberta. The techniques for coal production are also regionally specific. Western Canada coal is mostly extracted with surface mining techniques where as Maritime deposits are mined with underground techniques. Nearly all Canadian coal mines are surface mines (strip and open-pit), which generally have lower production costs than underground mines.

Coal Sector Profile

Vast additional coal resources below mining depth could become a valuable source of coal bed methane, as it has in the United States and elsewhere in the world (20% of current U.S. gas production). Potential methane resources based on preliminary geological information could be several times the total Canadian conventional natural gas resource base. Coal bed methane exploration and development are pursued in Canada by oil and gas companies, both large and small, which hold the rights to exploiting it.

Figure 14



The structure of the Canadian coal industry reflects its diverse geographic distribution and history of development. Ownership of the larger mines is concentrated in a few companies: Fording Coal Limited, Luscar Ltd., Manalta Coal Ltd. and Teck Corporation in the west (these four companies account for 80% of Canadian operations), and the Cape Breton Development Corporation (DEVCO) in the east. All the coal mines in western Canada are owned by private companies or electric utilities. In eastern Canada, DEVCO is a federal

Crown corporation and New Brunswick Coal is owned by New Brunswick Power, the provincial electrical utility.

The Canadian transportation infrastructure is key to the success of the export coal sector. About half the coal mined in Canada is used near the mine-site to generate very low cost electricity. The rest, as well as the coal imported from the United States, is transported over long distances by train and ship. Over 28 million tonnes of coal (about 41 percent of domestic production), worth $2 billion at the point of exit, were exported in 1993 mainly from ports in British Columbia and in Nova Scotia. Japanese and South Korean steelmakers are the main importers of Canadian metallurgical coal. Japanese and South Korean utilities are the main importers (over 80%) of Canadian thermal coal as well.

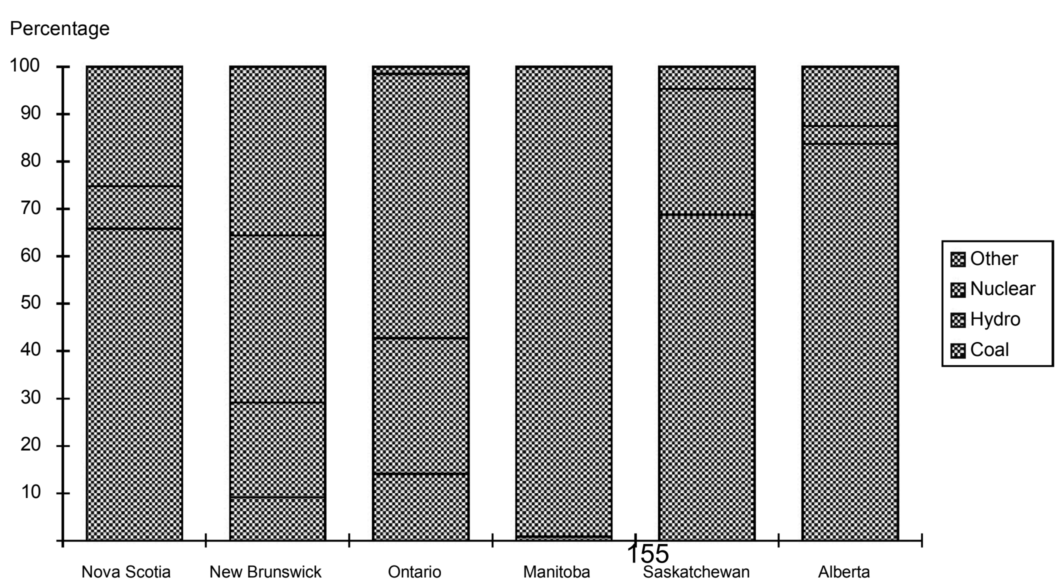
Coal Utilization

Coal is used by utilities to generate electricity and by the metallurgical industry to produce steel and primary iron. In 1993, Canadian utilities and the metallurgical industry consumed 43 and 5 million tonnes of coal, respectively.

Electric utilities in five provinces - Alberta, Saskatchewan, Ontario, Nova Scotia and New Brunswick - account for over 95% of Canada's thermal coal consumption (see Figure 15). In 1993, there were 26 coal-fired power stations with a total capacity of 17 gigawatts.

Figure 15

Electricity Production By Fuel Type - 1993



Electricity production from these coal-fired plants represented about 15% of all electrical energy production in Canada. Alberta, Saskatchewan and Nova Scotia produce most of their electricity from coal because they are endowed with large reserves of this fossil fuel. Ontario, which is the third largest thermal coal consuming province, imports about two thirds of its coal from the United States. The remainder is imported from western Canada. Ontario's use of U.S. coal is mainly due to the lack of local reserves and the high cost of transporting coal long distances across Canada.

The Ontario steel industry is the other significant user of coal. Canada's three major steel producers import about 5 million tonnes of U.S. coal. Other industrial coal users, who are concentrated in Ontario and Québec, consume on average less than 2 million tonnes a year, 60% of which is imported from U.S. suppliers.

Future Generation of Wealth

Coal Supply

Overall production of coal is forecast to double from 65 million tonnes in 1992 to 135 million tonnes in 2020. Improved efficiencies lead to increased productivity per worker, but the size of the predicted production growth will mean a significant increase in the workforce levels, at mines and in support activities.

Coal will continue to be a valuable export commodity. Trade in thermal coal is expected to continue growing. A considerable amount of this growth should occur in Asia. Canadian coal is well situated to compete there. By the year 2020, it is anticipated that Canadian thermal coal exports will increase from the current level of 4 million tonnes/yr to 16 million tonnes/yr.

Production of methane gas from deep coal seams could become a significant contributing energy source over the next decade. Coalbed methane now accounts for 20% of U.S. natural gas production. Although there is no significant Canadian economic production at present, potential in-situ coal bed methane resources could greatly exceed conventional natural gas resources. The fact that increased production of conventional gas will come from sour gas wells or from farther, more costly fields like the Beaufort Sea contributes to the potential future economic use of and industry interest in coal bed methane.

International markets for metallurgical coal will increase slightly over the next decade mainly because of increased steel production in developing countries. It is anticipated that exports of metallurgical coal will increase from the current level of 24 million tonnes/year to 29 million tonnes/year by the year 2020. Canada has opportunities to expand exports of metallurgical coals in developing countries but also to Europe and the United States because of technical and environmental advantages of some Canadian coals.

Coal Utilization

Coal will continue to play a major role in the Canadian economy. It will maintain its share of the electric power generation market in Alberta, Saskatchewan and Nova Scotia, and will continue to be an important feedstock for Canada's iron and steel industry.

Provincial utilities are meeting their commitments under federal-provincial clean air agreements and coal-fired generation will have to be cleaner than ever. Because of environmental concerns (such as greenhouse gases), the utilization of clean coal technologies will be the major solution for coal to compete with other energy sources such as natural gas and nuclear. Any significant resurgence of coal as an alternative to nuclear generation will be based on clean-coal technologies, and is not expected to occur until the post-2000 period. Nevertheless, domestic coal demand is expected to increase gradually beginning in the mid-1990's as existing thermal generation facilities become more fully utilized.

Demand for coal in the industrial sector, primarily in iron and steel production, could double by the year 2020 depending on the rate of implementation for advanced iron and steel technologies, for which many non-technical barriers must be overcome. The low cash flow of exporting companies has slowed their capital investments and their possibility of capturing new markets.

Sustainability Issues

Coal Supply

Even though coal resources are vast, knowledge of technological characteristics required by international buyers, in particular trace elements, must be improved to maintain and expand production. In some mature coalfields, mining must proceed to deeper, more expensive seams or move further away from power plants with a cost control issue. We must also ensure that exploitation proceeds safely and efficiently while respecting the environment. Coal companies in Canada have developed high standards for land reclamation and won many awards.

Research into more efficient technologies to lower mining costs and increase productivity contributes to Canadian coals' competitiveness in the global market.

Coal Utilization

Coal combustion accounts for about 20% of Canadian emissions of sulphur dioxide (associated with acid rain), 10% of emissions of nitrogen oxides (associated with acid rain and low-level ozone) and 21% of emissions of carbon dioxide (associated with the greenhouse effect). In response to public concern about the environment, Canada has developed more stringent domestic environmental guidelines and has participated in the development of a number of international agreements which will affect coal utilization and that of other fossil fuels.

The Canada-U.S. Air Quality Agreement commits Canada to a limit of 2.3 million tonnes of sulphur dioxide emissions in the seven easternmost provinces by 1994. The 1994 commitment applies to the eastern provinces only because this is where significant transboundary flows exist. By the year 2000, the cap under this agreement will be 3.2 million tonnes Canada-wide. Federal-provincial agreements to meet the 1994 target for eastern Canada mean that coal-burning utilities in Ontario, New Brunswick and Nova Scotia are making large capital investments to reduce sulphur dioxide emissions.

As stated above, the burning of coal (and other fossil fuels) generates carbon dioxide, which may have an effect on future global climate patterns. In 1992, Canada ratified the Framework Convention on Climate Change, which aims to stabilize human-induced emissions of carbon dioxide. In addition, the federal government believes that further reductions are required and has suggested a goal of a 20% reduction of 1988 levels by 2005. Because carbon dioxide emissions per unit of energy production are higher for coal than for other fuels (e.g., coal emits at the burner tip twice as much carbon dioxide per unit of energy as does natural gas), this commitment is of particular concern to the coal industry and utilities. The development and implementation of clean and energy efficient technologies is essential for the sustainability of the sector.

Discussions are also proceeding on an international protocol on heavy metals and organics emissions (trace elements). Although the discussions cover a wide range of sources (i.e., far more than just coal), any efforts to reduce these emissions could have implications for coal-burning power plants.

Coal Sector Profile

Characteristics of Innovation in the Sector

Coal Supply

Given the financial situation of the export coal industry, producers can support only short-term, targeted R&D projects. Fierce international competition and high inland transportation costs have created this situation. The majority of the R&D on supply is related to geoscience, environment and health and safety issues. Innovation occurring in coal mining is driven by competition and is international by nature. Most improvements do not show up in statistics, since they are carried out within operational budgets by mine employees in concert with equipment suppliers and contractors.

The domestic coal supply sector does support S&T projects related to toxics and other trace elements, to enhancing knowledge of its resource base and to productivity aspects of coal processing as well as remediation schemes for surface slope-designed waste piles. For the most part, there is little innovation occurring in surface coal mining technologies that the government R&D centres can support, partly because such innovations are international by nature.

Coal Utilization

A large part of the innovative research is in the adaptation of new clean coal technologies to the Canadian situation. Canadian R&D builds on the R&D efforts being undertaken in countries such as the United States. The main objective of Canadian R&D efforts is to ensure that Canada's growing demand for coal is met from domestic sources. Electric utilities are a major player in this area. The adaptation of new clean-coal technologies, such as the Point Aconi fluidized bed combustion system and the Belledune flue gas desulphurization system, are examples of this type of research.

Another area for innovation is the continual need, in the context of aging thermal power plants and more stringent environmental regulations, to retrofit devices for improving burning efficiencies and/or for reducing pollutants at existing facilities. This remains the most economic decision for power generation, because it stretches plant life and differs remediation costs associated with closure. Ontario Hydro retrofitted flue gas desulphurization at the Lambton Power Generation Station in 1993. The Canadian Electrical Association is very supportive of research related to repowering and retrofitting, and has initiated projects in this area in collaboration with the International Energy Association.

Potential for Technical Advancement to Support Wealth Creation

Coal Supply

R&D to improve the health and safety of underground coal mining is an area of strategic interest. In terms of health and safety issues, advanced geotechnical techniques, ventilation systems, and gas and dust monitoring would permit the safe exploitation of coal in Canada.

With respect to productivity, market competitiveness can be assisted through: advanced computerized geological models helping companies decide on how to mine a coal deposit to improve recovery and quality and to identify environmental constraints; and R&D on coal processing to improve mines' yield and reduce environmental pressures.

Inland transportation costs are quite high for several reasons. One is that coal must be carried over long distances to ports (for exports and electricity in Ontario). Another is the excessive regulation of the transportation system, which lowers competitiveness. Yet another reason, according to the coal industry, is the heavy tax burden imposed by federal and provincial governments. R&D would make a marginal improvement in the coal transportation infrastructure. However, the federal government would have to support most of the longer term research, because industry support goes only to technological improvements in a tight financial situation.

Coal Utilization

The current challenge is to develop and commercialize new clean-coal technologies and improve on existing technologies that increase efficiency and further reduce emissions so that coal can continue to be an attractive fuel option in Canada and around the world. Utilities, equipment manufacturers, consultants and the federal government are carrying out collaborative research activities in order to improve the efficiency of these technologies and make them cleaner. New coal burning processes are being developed or even tested around the world. Others are already commercially available. For instance, Nova Scotia Power has recently built a new coal power plant using a fluidized bed combustion system at Point Aconi, presently the largest one in operation worldwide. New Brunswick Power has successfully commissioned one of the cleanest coal fuelled stations in the world. Technologies used include a covered coal transfer and storage system, advanced particulate removal and wastewater treatment, and flue gas desulphurization and by-product utilisation.

Adaptation of the developing technologies is also needed in the case of existing power plants, to enhance efficiencies and reduce environmental impacts. Repowering, a serious low cost competitor to new plants, and retrofitting both require intensive R&D efforts because configurations of industrial plants change, furnace chambers geometry varies and environmental constraints evolve.

Other R&D areas to be addressed are: solid and liquid wastes released by the advanced combustion technologies; improved burner design for manufacturers (SMEs); and the control of trace elements emission in the environment. Resulting Canadian technologies and know-how would provide export opportunities in a growing coal market.

The competitiveness of Canadian steel companies depends on R&D to adapt new technologies (coal injection into blast furnaces, coal base smelting reduction processes). In addition, Canadian metallurgical coal producers could further benefit from additional R&D on Canadian coal characteristics and the development of international standards.

Ability of Industry to Capture Benefits

There exists a network of coal research performers involving the federal and provincial governments, utilities, the industry and other countries. The partners have then access to the results and apply them whenever they want. The issue is not one of the industry's ability to get access to new technologies, but the industry's ability to introduce the new equipment and processes into their operations. The ability of the coal industry to transfer and adapt technologies to their operations is wholly dependent on their economic health. Barriers are not necessarily technical. Major expenditures may be required by the coal producers, utilities, steel and other industries to improve their equipment and facilities.

Coal Sector Profile

Assessment of Federal S&T Capabilities

Profile/Impact of Current Activities

Current S&T activities cover science and technologies relating to coal geological assessment, mining, preparation (beneficiation) and, especially, utilization in heat production for power generation and steel manufacturing. The objective of coal research is to advance and promote the science and technology contributing to the safe, efficient, competitive and environmentally responsible development and use of Canadian coal resources.

Coal is the most abundant and widely spread source of energy worldwide. It is being used as a relatively inexpensive and efficient power generation means by developing countries. The Canadian coal industry must maintain its viability (especially in the international market) while respecting more stringent environmental standards domestically. Research aims at responding to this challenge by developing advanced techniques to assess coal resources in terms of quality, mineability and environmental constraints to development, by generating more efficient and safer mining methods, by creating better management practices for coal wastes and by improving beneficiation processes to increase the heating value of coal and reduce its sulphur and ash content.

A new domain of research is the assessment of methane resources of deep coal seams (coal bed methane or CBM) in Nova Scotia and in the Western Canada Sedimentary Basin. It is estimated that CBM resources are four to five times the conventional natural gas resources in Canada. The Geological Survey of Canada (GSC) is currently doing geoscientific research to determine the potential of this resource and to provide the exploration industry with data on this huge source of natural gas.

Utilities and the steel industry have scope to make their processes more efficient while limiting the environmental impacts. The federal government works with partners from both economic sectors and others to develop and improve technologies for electricity generation and steel-making processes, to develop realistic environmental protection criteria for coal utilization, and to control emissions and treat wastes from thermal plants. This way, coal will continue to be an attractive fuel option in Canada and the viability of the steel industry will be maintained. In addition, Canadian expertise could be used to assist developing countries by working in partnership.

The federal government is the most important player in coal research in Canada, mainly through the interdepartmental Program of Energy R&D (PERD). Natural Resources Canada (CANMET and the Geological Survey of Canada), Environment Canada, and

Coal Sector Profile

Fisheries and Oceans are collaborating closely with the coal industry, the utilities, the steel industry, the provinces and other countries through consortia and task- or cost-shared activities. Advice on coal research and industrial needs for coal related R&D are obtained through advisory committees and associations. The Independent Review Committee which comprises industrial, academic, provincial and federal representatives reviews annually the coal research program of the Geological Survey of Canada. The Minister's National Advisory Council to CANMET (MNACC) provides advice on the coal program of CANMET. The Coal Association of Canada, the Canadian Electrical Association, the Canadian Gasification R&D Committee and the Canadian Carbonization Research Association are significant in determining the direction of coal R&D carried out or supported at CANMET.

Most of the expenditures on coal research are currently devoted to coal utilization. Canada is also involved in collaborative research with other countries through the International Energy Agency and other agreements or memoranda of understanding.

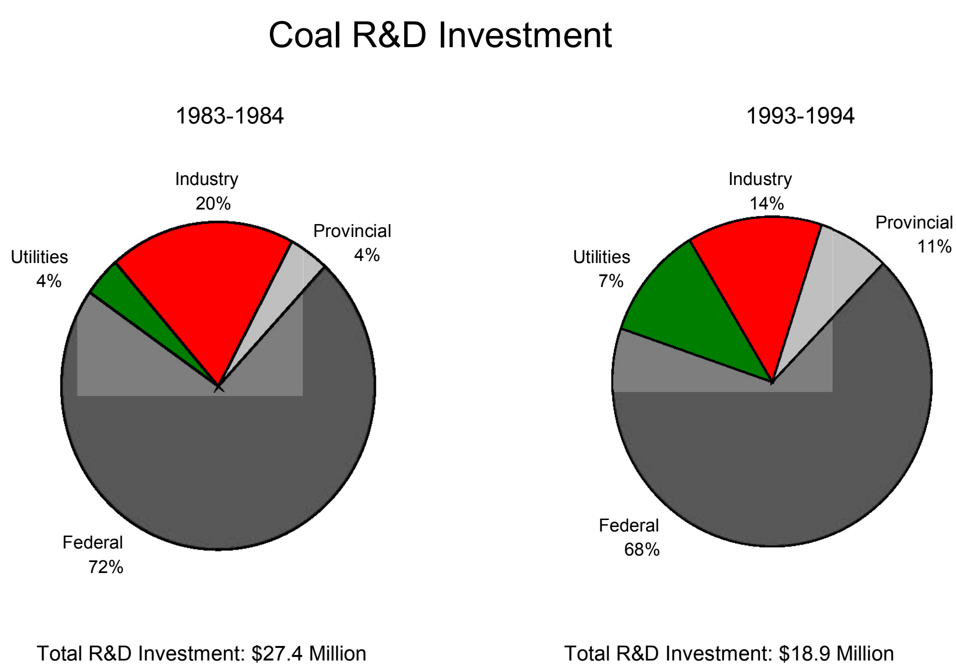
This collaborative approach has yielded economic and environmental benefits in various ways. For example, in the Estevan Coalfield of Southeastern Saskatchewan, computer modelling work on available industry exploration data has identified an additional 70 Mt of resources that could be recovered with a 20% increase in current mining depths, which would extend the life of the deposit by 65% and ensure supply for two mine mouth power plants. The value of this coal in situ is approximately $700 million. A second example is the development of safer and more efficient mining techniques in underground coal mines in Nova Scotia. It is estimated that annual savings in material costs will amount to $2.5 million, thanks to CANMET expertise. Another example is the investigation of pulverized coal injection (PCI) as a method to reduce the use of coke, increase the efficiency of the plant furnace and lower CO_2 emissions. CANMET, the Canadian leader in this domain, has preliminary proof that Canadian metallurgical coal can be used in PCI technology, which is being adopted internationally. The research is critical to the continued viability of the Canadian steel industry (worth $2.5 billion per annum, 19,000 jobs, potential savings estimated at $150,000 per year) and the export of metallurgical coal (worth around $2 billion per annum, 20,000 direct and indirect jobs in British Columbia and in Alberta). A last example is the research done by Environment Canada and CANMET (in a number of cases with CEA) to improve the efficiency and reduce the environmental impacts of coal power plants. This work has provided scientific knowledge to advise lawmakers on the development of regulations and policies, and helped the utilities comply with national environmental standards on emissions and wastes.

The technologies and expertise developed for coal can be applied to a variety of other areas. Software technologies developed for geological and economic analysis of coal deposits and coal bed methane can be utilized by the oil and gas sector to create sophisticated computer models of exploration targets which enhance exploration success. These technologies have also been applied to the assessment of potable water resources in the western plains, and to the assessment of mineral deposits including diamonds and pottery clay. These applications have been demonstrated by GSC staff to private sector groups including Gulf, Pan-Canadian, PetroCan and Canadian Hunter. As well, research on the treatment of effluent streams resulting from the beneficiation of coal will eventually be applied to treat large volumes of sludge produced from oil sands processing. Another example is combustion technologies such as fluidized bed combustion that could be used for municipal wastes, industrial wastes such as pulp and paper residue and contaminated soils and incineration. Such a system is fuel flexible, less polluting than conventional systems and can also be used in cogeneration schemes.

R&D Investment Trends

In 1983, the total expenditure on R&D for coal amounted to $27.4 million dollars, $18.9 million in 1993. Figure 16 shows the share of each participant for 1983 and 1993. Of the 1983 total, the federal government contributed $19.6 million and industry contributed $5.6 million. The provincial governments and the utilities were minor players contributing $1.1 million and $1 million respectively.

Figure 16



In 1993, the amount of money used for R&D in this area fell. The total investment was $18.9 million which is a decline of 31% since 1983. Both the federal government and industry spent less on R&D with the federal government contributing $12.8 million and industry contributing $2.7 million, a decline of 35% and 51% respectively. The federal government's contribution has declined a further 31% in 1994-1995 to $8.6 million. The reduced investment in this area is partly due to the financial climate being faced by government and industry. The poor financial state of the coal industry has resulted in significant reductions in visible R&D expenditures. Decreased federal investment in this area is primarily due to government efforts to reduce the budget deficit.

However, the provincial governments and the utilities increased their investment to $2.1 million and $1.3 million respectively. This translates into an increase of 88% for the provincial governments and 18% increase for the utilities since 1983. This increase can be attributed to two factors. First, several provinces rely on coal to generate their power and invested in R&D to find methods of using coal more efficiently. Second, the environmental concerns related to coal combustion, resulted in increased R&D by the provinces and the utilities to find more environmentally responsible methods of burning coal. Since that time, the government of Alberta has, for deficit reduction purposes, reduced its coal R&D investment substantially.

Nature of S&T Opportunities and Strategies

S&T opportunities to generate wealth exist in both the supply and the utilization sides of the coal sector. They would include coal bed methane, efficient and safe exploitation of coal resources, efficient and environmentally-acceptable combustion technologies, metallurgical coal and other high temperature processes.

Resource Analysis

The digital integration of exploration, coal quality and environmental information for Canada's coal resources will provide a knowledge base to establish resource availability and economic value given mining and environmental constraints, and to optimize coal supply planning by governments and industry. This knowledge base will also provide fundamental information required by international buyers and investors. Development of a similar knowledge base for coalbed methane is required to optimize industry expenditures and stimulate the early development of a coalbed methane industry in Canada.

Mining techniques

Mining techniques, especially for underground mines, still need to be improved in order to ensure safer working conditions to miners and enhance cost competitiveness through higher productivity and better equipment utilization. Advanced computerized geological models, air quality monitoring and control systems, more efficient mining equipments, improved mine design planning and robotics are examples of opportunities in this sector. With respect to surface mines, better practices for rock waste dumps in mountainous regions of British Columbia are particularly important to avoid landslides and minimize impacts on the environment. Automation and better diagnostics for maintenance also constitute important industrial development thrusts.

Trace Elements

The combustion of coal may release trace element compounds containing bromine, chlorine, heavy metals and radionuclides which may be hazardous to humans and other forms of life. Governments and utilities consider this issue as significant and research must address the distribution of these elements in Canadian coal deposits, the mode of dispersion in the environment and potential mitigating measures, either before or after utilization. The utilities have made significant contributions to R&D carried out by federal departments and industrial laboratories to determine the present extent of the problem of trace element dispersion into the environment. Health impacts will be evaluated.

Cleaner Coal Combustion Technologies

As future environmental standards will be more stringent, R&D must help utilities to continue burning cheap Canadian coal. Various countries including Canada are developing and improving advanced coal combustion technologies. Due to the large capital costs of new plants and lower demand for electricity in Canada at present, serious consideration is given to repowering and retrofitting. Utilities and the federal government support R&D activities to ensure that clean coal technologies can use Canadian coals and meet environmental standards. Research in this area will mainly focus on the adaptation of foreign technologies to the Canadian coals. Canada has been gaining expertise on combustion modelling and expert systems for highly-efficient and less polluting combustion processes that could be used both for new and existing power plants. This could then be exported to developing countries where demand for electric power will mostly be met by coal and will continue to grow at a rapid rate.

Metallurgical Coal

The metallurgical coal and steel industries deal in a highly competitive market where significant technological changes are occurring. On one hand, Canadian metallurgical coal producers must satisfy new specifications of coking coal consumers. On the other hand, our metallurgical industry must continuously improve its processes in order to maintain its competitiveness. R&D is required to support the development of efficient metallurgical processes, and to ensure that future international standards for coals are fair to Canadian coals. Development of analytical methods showing the high quality of Canadian metallurgical coals compared to those of other countries becomes critical. The Canadian

Carbonization Research Association contributes to financing and defining orientations as do individual companies.

Other Clean Coal Technologies

The residues from coal cleaning practices, solids from coal combustion and the emissions of methane as a greenhouse gas from coal mines need to be further investigated and mitigation technologies developed and implemented. The clean-up of combustion gases provides one means of reducing emissions from combustion systems. These technologies include flue gas desulphurization to remove sulphur dioxide, trace element removal strategies, selective catalytic reduction to remove nitrogen oxides or low NO_x burners to minimize its formation, and particulate removal systems. While Canada is unlikely to develop these clean air technologies alone, there is need to access and optimize these technologies to Canadian coals and conditions.

Benefits and Impacts

First, these opportunities would ensure that the forecast doubling of coal production in Canada is managed in a sustainable and environmentally responsible manner. Coal would continue to provide low cost electricity to industrial and domestic users in five provinces, and coal utilization would minimize environmental impacts. Secondly, exports of thermal and metallurgical coals would increase as Canada would still supply high quality coal, satisfying increasingly stringent specifications required by the international clients. Thirdly, metallurgical companies could still be competitive in recent and future trade agreements.

The benefits of the low cost electricity provided by coal include reduced production costs for the Canadian industry which enhances its competitive position in export markets, and has allowed other electricity-intensive activities such as the tertiary recovery from marginal oil wells.

Employment in communities depending on coal mining would be maintained in the short term and expanded with increased demand, and the transportation infrastructure (rails and ports), which is highly dependent on this commodity, would directly benefit from a healthy coal industry.

Some coal supply and utilization technologies would be applicable to other sectors, including the mineral and the petroleum (including oil sands) sectors, which would optimize exploration, extraction and utilization of these resources. More efficient and safer mining techniques could be applied to other mineral sectors. Sludge treatment, in particular the separation of organic materials from water, could be used by the pulp industry, by oil sands companies and by the food industry. Advancements in combustion technologies could be applied to waste management. Finally, the Canadian expertise could be exported to developing countries.

S&T Capabilities

As mentioned in the sector profile, the coal industry (especially the metallurgical coal exporters) is in a survival mode and is slowly recovering. They cannot support research independently. The metallurgical industry includes a small number of large companies. The federal government is currently the most important performer of coal R&D, especially for coal utilization.

CANMET, the main energy research and development organization within NRCan, possesses unique facilities to respond to industry needs. This expertise includes: the Cape Breton Coal Research Laboratory in Sydney, Nova Scotia, which carries out research on underground coal mining; the Energy Research Laboratories in the National Capital Region which address technological and environmental issues regarding coal combustion, gasification and carbonization; and the Western Research Centre in Devon, Alberta, which does R&D on tailings management and coal beneficiation.

The Institute of Sedimentary and Petroleum Geology within the GSC is the other important coal R&D performer of NRCan. This organization has a unique computer hardware and software infrastructure and computer modelling and trace element expertise utilized in the development of the digital National Coal Inventory.

Other R&D players, Environment Canada and the department of Fisheries and Oceans, contract out much of their research activities on coal, most of the time in collaboration with the Canadian Electrical Association and members. Environment Canada has been very successful in identifying and assessing world class coal environmental protection technologies and providing guidance for their application in Canada. This has resulted in Environmental Codes of Practices and Emission Guidelines which have been implemented by utilities, and has developed S&T capabilities in the private sector.

This research infrastructure has been built in consultation with the clients to meet their needs. The forecast doubling of coal production in the next 25 years demands a continued R&D effort to maximize the competitive position of the industry internationally, and to mitigate the environmental consequences of increased coal use. However, the current budgetary context of the government threatens it and a serious risk exists to reduce heavily the expenditures in this domain below the critical mass needed to maintain a viable R&D program in support of Canadian industry.

Strategy to Do Research

The federal government will have to support most of the research on the supply side until the coal industry recovers. However, the utilities, equipment manufacturers, consultants and the metallurgical industry should be encouraged to support a greater part of the research devoted to coal utilization. The best strategy is to continue the current approach consisting of collaborative research with the private sector. Consultation should still take place and R&D involving the financial participation of the private sector should be encouraged within the federal government. Maintaining ongoing collaboration with the provinces would avoid the risk of duplication of efforts.

An example of work being carried out in this way is the R&D activities supported by the Canadian Electrical Association and its members, in partnership with CANMET and Environment Canada to develop technologies to reduce emissions of acid rain and smog precursors (NO_x and SO_x) and greenhouse gases (CO_2 and N_2O). These include scrubbers, novel low NO_x burners and heat and power co-generation systems.

Universities should be encouraged, through vehicles such as the NSERCC Strategic Grants for Energy, to carry out more fundamental research on coal. Therefore, they would constantly provide new scientific concepts to the research community that could complement government laboratories own ideas. Research facilities such as CANMET's should look after the development of applications from these new concepts in consultation with the private sector to ensure that results are quickly transferred to its clients.

The current international consultation through the International Energy Agency and other organizations will continue because Canada is a small coal R&D performer. International Energy Agency (IEA) consortia exist in the area of coal combustion science, flame characteristics, and coal characterization respectively. Such collaboration gives Canada access to the knowledge acquired by the more active players; e.g. the United States. Canadians sit, as well, on international standards committees for combustion data acquisition or coke tests, because of expertise and to represent Canada as a nation. Another reason is the fact that the major niche for our country is to adapt foreign coal technologies to the Canadian situation, although Canada also maintains a leading edge on a number of technologies.

The federal government will continue to coordinate and bring together stakeholders to pool resources and share knowledge.

Coal Sector Profile

Future Indicators of Federal S&T Impact

There are presently a number of ways to measure successes of R&D investment in the sector. An example is the PERD success stories measuring economic return of selected projects. Two types of indicators could be used to measure the impact of the federal expenditures on coal-related research.

Technological Indicators

This kind of indicators refers to the technological progress accomplished so far. The first indicator would consist in evaluating the yearly coal consumption per unit of energy produced from coal power plants in Canada. If the data showed a stable or decreasing coal consumption while meeting the domestic demand for electricity generated from coal, it could be argued that the efficiency has increased. The same logic could be applied to the release of emissions and wastes from thermal plants to illustrate their environmental improvements.

Socio-economic Indicators

The other type would deal with indicators assessing the impact on the economy and society. They could include:

- the number of jobs directly related to mining, transportation and utilization of coal (e.g. steel industry);
- job creation;
- the economic health of communities whose existence is based on coal;
- reduced number of accidents in coal mines;
- improved air quality in communities whose existence is based on coal production or use;
- sales of manufactured goods related to coal use;
- income to consultants and design groups;
- increased exports; and
- leverage in the research sector.

Coal Sector Profile

Synopsis: Coal

Importance for Wealth and Job Creation

- Coal is the most abundant and widely distributed fossil fuel in Canada, comprising more than 80% of fossil fuel energy with an in situ value of more than $65 billion. Sustainability stems from the large resource base, more than 200 years at present consumption rates.

- It is primarily used as feedstock in the production of primary iron and steel (Ontario) and as a main source of energy for electricity generation, supplying 17% of all electrical energy production in Canada (Alberta, Saskatchewan, Ontario, New Brunswick and Nova Scotia).

- The domestic-oriented thermal coal industry is forecast to grow substantially over the next 25 years, which will result in growth of total Canadian coal production from the present 69 million tonnes/year to 135 million tonnes/year.

- Coal is a very competitive fuel for domestic thermal power generation. Its low cost of conversion into electricity has provided stable energy costs for industry and permitted the profitable development of activities based on intensive electrical use and the creation or maintenance of a large number of jobs in Canada.

- Coal is a valuable export commodity ($2 billion in 1993). Its diverse technological characteristics can compete favourably against other world suppliers in the growing thermal coal market as well as in the mature metallurgical coal market for both coke and coal injection.

- The export-oriented metallurgical coal industry is presently in a survival mode. Recent restructuring has been necessary to remain competitive. Its financial situation is still precarious, though improving.

- The international market for thermal coal is forecast to increase substantially, which will result in export opportunities for Canadian producers. Thermal coal exports are forecast to grow from the present level of 4 million tonnes/year to 16 million tonnes/year by 2020.

- Resulting Canadian technologies and know-how would provide export opportunities in a growing coal market.

Coal Sector Profile

Future S&T strategy

- Research must continue to be carried out with the participation of the coal industry, utilities, equipment manufacturers and metallurgical sector in order to ensure that R&D activities meet their needs. Federal Energy and Environment agencies should continue to collaborate on the sustainable development of coal S&T, particularly for reducing impact of coal power generation.

- On the supply side, assessment of thermal coal resources must be carried on to enhance the knowledge base on technological and economic characteristics and environmental constraints to development in order to sustain the forecast growth in this sector and help decision makers optimize resource development. R&D to improve the health and safety of underground coal mining is an area of strategic interest. However, the federal government would have to support most of the research until the industry recovers. Fine coal recovery can be industry supported for wealth generation.

- The current challenge in coal power generation is to develop and commercialize new clean-coal technologies that increase efficiency in conversion to useable energy and further reduce emissions (NO_x, CO_2, SO_2, N_2O, toxics) so that coal can continue to be an attractive fuel option in Canada and around the world. Research is in the adaptation of new clean coal technologies to the Canadian situation as well as in retrofitting new technologies to aging power plants. Electric utilities, equipment designers and manufacturers, CANMET and Environment Canada are major players in this area.

- The competitiveness of Canadian steel companies depends on R&D to adapt new technologies. In addition, Canadian metallurgical coal producers could benefit from additional R&D on Canadian coal characteristics and the development of international standards.

- Continued demand by Canadians for improved industrial environment means that another option could be to investigate the benefits of cleaning coals before combustion, as an alternative to flue gas treatment, in order to optimize the cost of power generation from coal. Both feasibility and best choice need to be considered for each power plant location and conditions of operation. Much R&D work is needed to reach a better understanding of choices and permit industry to make an enlightened decision.

- Inland transportation costs are quite high in Canada. However, R&D would make a marginal improvement in the coal transportation infrastructure.

Sector Overview

Introduction

The Canadian nuclear industry, with AECL as its nexus, includes electric utilities, uranium producers and processors, engineering, manufacturing and construction sectors, as well as researchers, public administrators and consultants. No single Canadian private sector firm has the capability and basis to provide leadership for this industry. Instead, the federal government provides leadership and research (through AECL) for the industry. AECL does the R&D, keeps the product current and maintains the expertise needed to undertake large CANDU projects.

As an integral part of the nuclear fuel cycle, uranium supply is of strategic importance to most industrialized countries. Since nuclear programs are principally intended to diversify the supply of energy and to increase overall energy security, access to secure uranium supplies is critical to their success.

The nuclear energy sector comprises nuclear fission power generation, fusion, and the uranium supply sector. Nuclear power generation from fission reactors and uranium production are commercial realities today. Fusion is still at the R&D stage. Nevertheless, fusion research is being pursued to develop a future energy source.

Nuclear electricity generation is making a significant economic contribution to Canada's energy sector, and it is a sustainable energy source. The generation of electricity uses very small amounts of uranium, which has no other significant uses. It generates less waste than any other energy source; and emits no acid gases, greenhouse gases or particulates. The fuel cycle has been essentially closed from the outset. Wastes are stored at the power generating sites and costs have been internalized. In addition, the fuel wastes can be recycled. Nuclear energy is unique in this regard.

Nuclear energy is an alternative to carbon-based energy. The Canadian CANDU system could play an important role in global sustainable electricity generation in the future. According to an Angus Reid poll (June 1994) public support for nuclear energy in Canada is increasing, and a majority of Canadians (52%) support the use of nuclear power as one of the ways of producing energy in our country.

Despite the advantages of nuclear energy, there are still however concerns, especially about waste management.

Key Dynamics of the Sector

Nuclear Industry

In 1993, nuclear power represented about 17% of electrical energy production in Canada. Total installed nuclear capacity is about 16 gigawatts (GW). Nuclear reactors are used to generate electricity in three provinces – Ontario (about 60% of electrical energy generation in 1993), New Brunswick (30%) and Québec (3%). Ontario has 20 operating CANDUs, and Québec and New Brunswick each have one operating CANDU.

The Canadian nuclear industry makes a major contribution to the Canadian economy:

- It generates electricity and other goods and services valued at about $6 billion annually (based on estimates for 1993).

- Direct employment in 1992 is estimated at about 30,000 jobs. A minimum of 10,000 jobs in other sectors indirectly depend on the nuclear industry.

- Private sector companies which supply nuclear products and services had total sales of $9.4 billion between 1988 and 1992.

- The federal government receives approximately $700 million annually from the nuclear industry in the form of income and sales taxes.

- Canada's nuclear industry had a trade surplus of approximately $500 million in 1991.

- Ontario Hydro estimates that, from 1965 to 1989, nuclear energy has saved the Canadian economy approximately $17 billion in foreign exchange (i.e. largely foregone coal or oil imports.)

Nuclear power is used by both advanced and developing countries. However, most countries lack a domestic nuclear supply capability and rely on imports of goods, services and expertise from countries that have developed an indigenous nuclear industry.

Nuclear suppliers are generally located in advanced countries (which have developed indigenous nuclear technology, i.e. the United States, France, Germany, Canada, the former Soviet Union, and, more recently, Japan) and compete very aggressively for export orders. Canada was late into the market with the CANDU system but competes very well in openly competitive markets (i.e. markets outside the countries that have indigenous nuclear capability). As of December 31, 1992, 32 of the 427 reactors in operation world-wide were pressurized heavy water reactors based on the CANDU concept. Most of the remainder were Light Water Reactors (LWRs) based on original American designs, either Westinghouse-type Pressurized Water Reactors or General Electric-type Boiling Water Reactors.

A number of countries that have adopted the LWR concept from the U.S., notably France and Germany, have moved ahead with their own nuclear programs and designs, and are competing with the U.S. for export orders. Japan has just recently entered the international nuclear reactor market, based on advanced designs developed jointly with American partners. The Canadian CANDU reactor design is unique and virtually the only design that originated outside the U.S. which is still being offered commercially for export.

Uranium

Canada has significant "known resources" of uranium of current economic interest including some of the world's premier uranium deposits. Canada is the world's leading supplier of uranium and accounted for 28% of world output (about 9,200 tU) in 1993, with an estimated value of some $500 million. Saskatchewan alone accounted for 26% of Western world output.

Since only about 20% of Canada's uranium production is needed for domestic purposes, the balance is available for export to countries that meet the federal government's non-proliferation requirements. Since the mid-1960s, Japan, the United States and Western Europe have been of roughly equal importance as export markets. However, exports to the U.S. have become increasingly important in recent years.

Western world demand for uranium in 1992 was about 51,000 tU, while Western world output, including imports from the Former Soviet Union (FSU), approached 37,000 tU. The balance comes from accumulated inventories.

Unlike other energy commodities in Canada, uranium comes under the exclusive jurisdiction of the federal government pursuant to the Atomic Energy Control Act. Although the provinces own the uranium (just as they own the other energy and mineral resources), under the declaratory powers of the Constitution the federal government regulates virtually all aspects of uranium production, transportation and distribution.

Uranium is also unique in that it is an internationally traded commodity that, essentially, has a single peaceful end-use - as a fuel for nuclear reactors. To ensure that peaceful use is the case, trade in uranium is based on restrictions set out in international non-proliferation agreements, (again unlike other energy commodities). The implementation of these restrictions requires both a national policy regarding the export of uranium and government involvement in export approval (government to government accounting for the movement of uranium through the fuel cycle).

Fusion

Fusion represents a longer term option for generating electricity. The fusion fuels will be deuterium and tritium, isotopes of hydrogen, which Canada knows how to produce and handle because of the CANDU program. The major industrialized countries of the world currently invest about $2 billion per year in fusion research. Because fusion research is very expensive, the major players (USA, Japan, Europe, Russia) are co-operating on the next major developments in fusion technology through the International Thermonuclear Experimental Reactor Program (ITER).

Canada has a small fusion program of about $25 to $30 million per year, (roughly 50% federal - PERD - and 50% utilities), consisting of: tritium technology, based on the expertise developed in the CANDU program by Ontario Hydro and AECL; and reactor science and technology developed by Hydro-Quebec based on its high power electrotechnology expertise. The program is focussed on the ITER activity. By contributing in these key areas, Canada obtains access to the knowledge and the markets associated with the global R&D effort.

Future Wealth Generation

Nuclear Industry

In Canada, there are no new domestic orders for nuclear plants, and present indications are that no province plans to introduce new nuclear stations in the next 10 years. Ontario, the largest user of CANDUs, has a moratorium on new nuclear orders. New Brunswick Power continues to view nuclear power as an important option for long-term electricity supply. However, because of anticipated low growth in electricity demand, the utility's forecasts show that new base load capacity will not be needed until the year 2005, and discussions toward its next CANDU have therefore been put on hold. (For a nuclear plant to be in service in the year 2005, a commitment would have to be made within the next three to four years.) The province of Saskatchewan and AECL entered into an agreement to jointly develop the CANDU 3 design, for possible future introduction in that province. However, no firm plans for construction of a CANDU are in place.

Two Canadian-supplied CANDUs of AECL design are operating outside Canada, one in Korea and the other in Argentina. Four CANDU reactors are currently under construction – three in Korea and one in Romania (the latter is part of the planned five-unit Cernavoda station, only one of which is currently financed to completion). Sales of CANDU reactors are fully commercial (i.e. not subsidized), the most recent four sales having a value to Canadian industry of more than $1.5 billion. Korea is providing its own financing for its CANDU purchases while Romania received non-concessional Export Development Corporation financing in 1991 to enable completion of its unit.

New nuclear capacity over the next few years is likely to be limited mainly to France and the Far East (i.e., Japan, South Korea, Taiwan, Indonesia, and China). Turkey is also considering adding nuclear plants to its system. In the United States, significant growth in capacity is not expected until a new generation of advanced reactors with more passive safety features, that will be pre-licensed, is developed later in the decade.

Korea has shown interest in two additional CANDU units (over and above the three now under construction) coming into operation early in the next century, implying that orders will have to be placed within a few years. However, a new reactor design larger than the CANDU 6 may be required to secure these sales. AECL is working with Korea to design a reactor of 900 MWe or more, based on the standard CANDU design but incorporating principles developed for the newer 450 MWe CANDU 3.

Romania would like to proceed with the remaining four units at the Cernavoda site (in addition to the unit now being completed by a Canadian-Italian consortium). Financing is the difficulty, and current discussions are focused only on a second unit, for which some of the components were already built during the old Romanian regime and are in storage at the plant site.

Turkey is moving towards ordering a nuclear power station, perhaps in 1995 or 1996. Although competition will be stiff, AECL believes it is in the lead position. It has made a preliminary financing arrangement for its bid in collaboration with the Export Development Corporation and international partners.

Several other countries have expressed varying degrees of interest in the CANDU, and some of these prospects could develop in the intermediate term. Chinese interest is particularly keen at present.

Although there have been few international reactor sales recently, AECL has done extremely well with its recent orders in Korea and Romania and has emerged as a serious contender for capturing future reactor sales. Notwithstanding the relatively few reactor sales, the unit value to the Canadian economy is high, and prospects for further sales are improving.

Uranium

Uranium requirements will experience slow but positive growth through 2010. Since global supply is currently less than two-thirds of requirements, with the balance coming from inventories, new sources of production will be required by late in the decade. Canada is well placed to meet this challenge. However, there is a potential for a significant supply/demand imbalance in a few years' time, given that resources associated with certain key production centres will soon be depleted, and current spot prices do not justify new investment.

The emergence in 1988 of the former Soviet Union (FSU) as a major force in the world uranium market represents the principal economic uncertainty facing this market today. Although FSU uranium production has declined, the FSU continues to produce substantially more uranium than is required by its republics. The market uncertainty has been exacerbated by the fact that large quantities of uranium may become available from the FSU as nuclear weapons are dismantled, adding to the already very large commercial FSU inventories.

The future market for Canadian uranium will be seriously affected by the uncontrolled influx of FSU uranium into world markets. U.S. efforts to encourage liquidation of FUS commercial and military inventories, thereby providing hard currency for Russia, are the subject of a Canada/U.S dispute with NAFTA. Market uncertainty can be minimized if the United States and Russia would agree on more equitable trade rules.

Also contributing to recent short-term uncertainty for uranium producers is the joint federal-provincial environmental assessment and review of further uranium developments in Saskatchewan. In 1993, three uranium mining projects cleared the review process and will proceed, subject to the Atomic Energy Control Board's licensing process. These projects are needed if Canadian production is to be maintained beyond the mid-1990s.

Despite these uncertainties, Canada's uranium producers are competitive and well-positioned to meet the future. With significant potential for the discovery of additional uranium resources, and with policies in place to secure fair access to world markets, and to encourage investment in the uranium industry, Canada has the capability to maintain its position as the world's leading exporter, remain a reliable and competitive supplier to its trading partners and meet domestic needs for many years to come.

Fusion

The development of fusion reactors as practical energy sources is expected to take about 30 years. To achieve this goal, the world fusion community is engaged in large co-operative experimental and development programs, such as ITER. The Canadian fusion program is closely connected to these international ventures, which gives Canada access to a vast range of fusion technologies.

At present, Canada possesses unique capabilities in fields such as tritium technology, remote handling and electronic control systems. Our links to the wider fusion community provide opportunities to market these capabilities within the $2 billion international activity. Wealth creation in the short to medium term will result from these sales to the research market, and from technology spinoffs to other sectors.

Sustainable Development Issues

Nuclear electricity generation is clean and burns a fuel that is abundant and has no other peaceful practical uses. Nuclear power generation does not emit the pollutants associated with fossil-fuelled generation. Thus nuclear power has an important role to play in sustainable development programs. The quantities of used fuel and other radioactive wastes from nuclear reactors are very small, are contained, and concepts for their ultimate disposal have been developed. Nevertheless, the industry recognizes that there remain concerns about the long-term disposal of these wastes.

Currently, all Canadian high-level radioactive waste is stored at the nuclear reactor sites, where they are generated. Safe storage at these sites is viable for 50 years or more. At this time, less than 3,500 m^3 (the size of an Olympic swimming pool) of high-level radioactive waste is being stored in Canada. AECL Research company, in partnership with Ontario Hydro, Hydro Quebec, and New Brunswick Power, has been studying a concept for permanent disposal of nuclear fuel waste in a deep (up to 1,000 m) underground disposal vault in the stable granite rock of the Canadian Shield. This approach is believed to be technically sound and the concept is now being reviewed by an Environmental Assessment and Review Panel, which is expected to report by late 1995 or early 1996.

Uranium and thorium resources are abundant. (Thorium is not currently being used on a large scale - only India burns some thorium in its reactors - but its use may be expanded in the future, and it has the potential to extend the world's nuclear fuel resources significantly.) Recycling of nuclear fuel, while not currently being done in Canada, could extend uranium, and, ultimately all nuclear fuel resources, by a factor of 50 or more, providing a secure fuel supply for many centuries. Uranium mine tailings, produced from uranium mining, milling and fabrication, contain residual amounts of uranium, thorium and radon. which must be strictly controlled to prevent surface and ground water contamination. Some sites are of concern.

Fusion could contribute significantly to sustainable development if commercial competitive fusion reactors can be developed. Fusion will use abundant deuterium and tritium as fuel and will not produce acid gas emissions, nor significant amounts of long lived radioactive wastes. However, commercial fusion power is at least 30 years away.

Characteristics of Innovation in the Nuclear Energy Sector

The CANDU system is one of Canada's major scientific and engineering innovations. Canada is also one of the few countries in the world that is a full-service nuclear supplier. Canadian capabilities in the uranium sector include uranium mining, refining and conversion, fuel fabrication, and waste management. AECL has collaborated with utilities and many highly innovative small firms in the private sector to form a fully integrated industry.

Apart from the CANDU system per se, AECL has, over the years, transferred technology to the private sector and has contributed to setting up a number of viable enterprises. Examples of significant examples of such technology transfer, licensing, and spin-off cases are covered in the section on federal S&T impact.

Most of the technological expertise related to uranium is resident in the federal government in NRCan. Extensive liaison with the producing companies ensures technology development and transfer in areas of prime concern such as mine tailings.

Some of the most innovative high technology firms in Canada participate in the fusion program, with the Centre canadien de fusion magnétique (CCFM) and the Canadian Fusion Fuels Technology Project (CFFTP) acting as focal points.

This approach to the development of the nuclear technology in Canada, whereby a government funded agency acts as the focus for a number of small firms and assists them in developing and marketing their products, is in itself a highly innovative approach to technology development and international marketing.

Potential for Technological Advancement to Support Wealth Creation

Canada has considerable short-term prospects and orders for exports of nuclear technology. In addition to CANDU reactors, these include sales of heavy water, radioisotopes for medical applications, cancer therapy equipment, food irradiators, training simulators and engineering and contract R&D services, in particular in the environmental sector, where AECL's expertise in nuclear fuel waste management can find application in other industrial sectors as well.

Continued R&D will lead to advancement of the CANDU technology. Advanced CANDU products will produce electricity more economically, will have shorter construction times, perform more reliably, be easier to inspect and maintain, have a longer plant life, be even safer than current generation nuclear reactors, and should be publicly more acceptable. Canada's nuclear competitors are also currently developing their next generation products, and Canada must, therefore, continue its R&D efforts in this area if it is to remain competitive in future nuclear markets. The international market is difficult to forecast. However, environmental pressures are expected to force many countries to switch to more nuclear capacity in the future. This could result in new markets, beyond those mentioned in earlier sections of this report.

Continued R&D is necessary for regulations and safeguards and could alleviate the concerns in Saskatchewan about undesirable environmental impact. The development of fully automated small-scale mining equipment for uranium mining could reduce costs and concerns. Such equipment would also be applicable to other hazardous locations.

Continued technology advancements in areas such as gas separation, materials, cryogenics, remote handling, communications links, diagnostics in the fusion program will permit spinoff into other areas leading to an increase in productivity, reduced emissions and reduced input costs.

Strategic Needs

Given the potential for nuclear based electricity generation, coupled to end use electro-technologies, to reduce production of greenhouse gases and acid precipitation, there is a need to ensure that we do not foreclose this option but, in fact, promote it.

Demand will continue in Canada for sophisticated nuclear research and engineering facilities to ensure the safe operation of existing reactors; to provide for timely repairs in the event of malfunctions; to improve and advance future CANDU products; to carry out research on waste disposal options; and to undertake research needed by the federal government to discharge its comprehensive regulatory responsibilities in the nuclear area.

There is, therefore, a strategic need to continue to fund nuclear research. Basic to this need are adequate experimental facilities. Bearing in mind that Canada's only high-flux research reactor (NRU) is not expected to operate much beyond the year 2000, a new research reactor is essential to Canada's long term competitiveness in this sector.

The nuclear technology presents one of few options for large scale electricity generation that is sustainable in the long term. It is a technology that has given Canada entree into foreign high-tech markets and has given the Canadian government a prominent role at the international negotiating table on nuclear disarmament. Continuing R&D are essential to maintain and further advance these options for Canada.

The strategic need in uranium production is to alleviate public concerns about mine tailings and mining risks by developing the knowledge base and new fully automated mining technologies.

Although commercial fusion power applications are about 30 years in the future, the potential long term benefits merit continuing investment in this technology to maintain a critical mass of expertise, capture more of the international fusion experimental equipment market and spinoff technologies into other areas such as energy efficiency.

Ability of Industry to Capture Benefits

As pointed out earlier, the nuclear industry is fully integrated in Canada, with AECL acting as the nexus of this integration. This industry has the necessary linkages to take new S&T developments from the lab to the market and is, therefore, fully capable of capturing the benefits of advancements made by AECL and by other countries. This is evidenced by the fact that the CANDU technology is an indigenous Canadian technology that evolved over decades consistent with Canada's capabilities. Today, the goods and services embodied in the CANDU system are close to 90% Canadian. In light of this, Canada is well placed to capture the future benefits of this sector.

Canadian producers have the capability to maintain their world-leading position, but sizeable inventories still overhang the market, making it difficult to secure long-term contracts and justify new investment. However, fully automated mining equipment could be high priority as the market improves in the future.

CCFM and CFFTP have well organized networks to assist industry to develop and market fusion technologies. The transfer of fusion technologies to other fields such as energy efficiency would require assistance to evaluate and develop the technologies for specific applications.

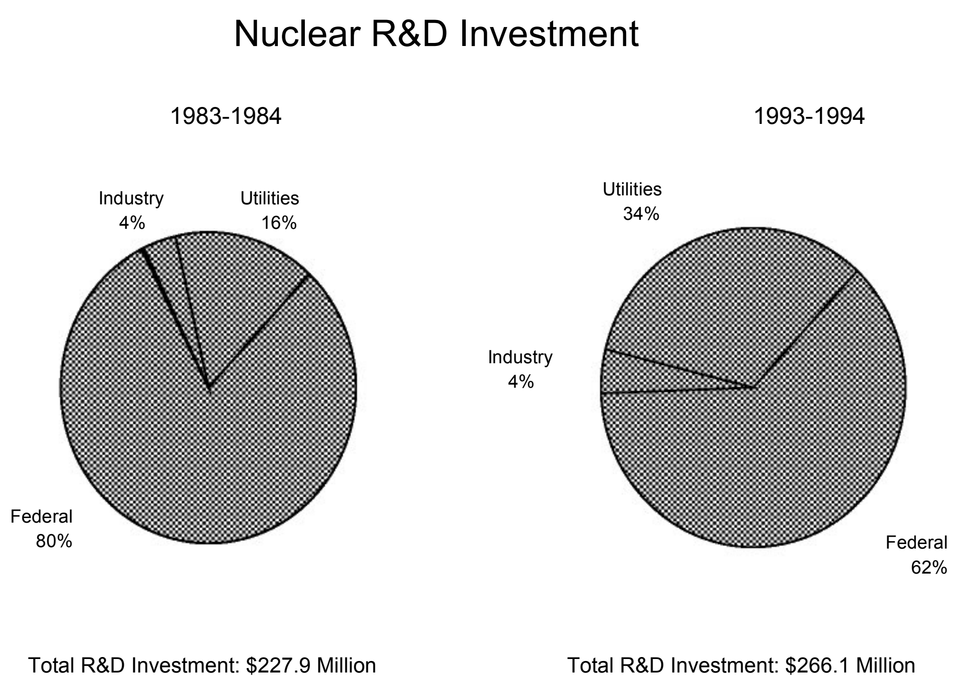
Assessment of Federal S&T Capabilities

Profile/Impact of Current Activities

R&D Investment Trends

In 1983, a total of $227.9 million dollars was invested in nuclear fission and fusion R&D. Figure 17 shows the percentage share of each participant. The federal government supplied $183.3 million, the utilities contributed $35.6 million while industry invested $8.7 million. The provincial governments did contribute to R&D in this area but the amount was quite insignificant; they contributed less than 1% of the total. The bulk of the research was directed towards exploration and generation but some of this research was directed towards fusion; the federal government contributed $10.3 million to fusion research in 1983.

Figure 17



The amount of money invested in nuclear R&D did increase over the last decade. Total investment reached $266.1 million, an increase of 16.8%. Industry and the utilities both increased their total investment. In 1993, industry and the utilities invested $101.5 million to nuclear R&D. These figures represent increases of 129%. However, the federal government remained the largest contributor. Also, the federal government invested $12.4 million in fusion related R&D.

Nuclear (Fission) Energy

The federal government's (AECL's) S&T objectives are: i) to advance the underlying knowledge required to support Canada's 22 operating CANDUs for the duration of their operating life, ii) to enhance the CANDU technology to ensure its long term competitiveness, and, iii) in the capacity as Canada's *de facto* national nuclear laboratory, to develop underlying knowledge in energy, environment, and health that enhances CANDU business prospects or supports Canada's nuclear policies and initiatives. With respect to Canada's nuclear fuel waste management program, AECL, with the support of the utilities, aims to maintain the technology until such time that utilities decide to proceed with permanent disposal of its spent fuel.

The federal government shares in the funding of R&D that supports the entire Canadian nuclear power industry. The R&D is performed largely by AECL. None of the nuclear component manufacturers have any substantive R&D capability, and therefore depend on the R&D performed by AECL. Areas investigated are: nuclear fuel and fuel cycles, reactor safety, reactor materials, out-reactor components and materials, information technology, heavy water and tritium, constructability, waste management, and basic sciences related to energy, health, and the environment. AECL's annual budget of about $300 million (some of which is expended on non-CANDU related R&D) is funded from three sources: the federal government (50%), Canadian nuclear utilities (30%) and commercial work (20%). The funds provided by the utilities are limited to use for R&D in support of existing CANDUs. Under cost-sharing arrangements with the CANDU Owners Group (COG), these funds are matched by AECL using federal R&D funds. Therefore, only about 20% of AECL's total R&D budget – or about $60 million – is available for research related to advancement of the CANDU technology and for research in basic sciences. Ontario Hydro, Hydro Quebec, and New Brunswick Power provide the utilities funding. AECL performs the R&D, designs, engineers, markets, sells, builds, and services CANDU nuclear power plants.

The clients are principally electric utilities in Canada and in export markets. The federal government is a major client for AECL's basic science and nuclear technology, as this assists Canada in formulating and pursuing international strategies related to this technology (e.g. international safeguards).

Partners are, currently, the members of the CANDU Owners Group (primarily Ontario Hydro, Hydro Quebec, and New Brunswick Power), who cost share the federally funded CANDU related R&D,and whose members are also clients for AECL's commercial work. AECL has also formed alliances with Canadian and international engineering, manufacturing, and construction companies to pursue reactor sales in foreign markets.

Other stakeholders are the more than 150 equipment manufacturers, as well as architect-engineers and consultants (in particular Canatom, whose parent companies are SNC-Lavalin and Monenco-Agra), that are suppliers to the nuclear industry. More than 100 researchers from Canadian universities, as well as scientists from abroad, have become stakeholders and are dependent on AECL's facilities, in particular the operation of NRU, TASCC, and other major experimental equipment.

The nuclear medicine community, radioisotope suppliers, and radio-pharmaceutical companies are important stakeholders and are dependent solely on the operation of NRU for their supply of isotopes.

The impact of AECL's CANDU S&T has already been noted under Key Dynamics. Apart from the impact of the CANDU system per se, AECL has transferred technology to the private sector and established a number of viable enterprises. Examples include:

- Fuel technology was transferred to GE Canada and Canadian Westinghouse, now Zircatech. Currently the two companies share a total annual market of $150 million supplying CANDU fuel and fuelling machines to existing reactors.

- The expertise gained from business within the Canadian nuclear industry originally based on AECL steam generator technology has placed Babcock & Wilcox International (B&W) at the forefront of the international nuclear steam generator market with yearly bookings in the $600 million to $800 million range. In 1992, B&W won 70% or 14 of the replacement steam generation contracts awarded in the USA, in competition with Westinghouse and Siemens.

- For many years, the Canadian nuclear industry has provided major contracts to Sulzer Bingham Pumps to supply pumps for the CANDU reactors, once again based on expertise originating from AECL. The company has recently secured contracts to manufacture pumps for the new South Korean CANDU 6 units and exports currently account for some 70% of total sales.

- Velan designs, manufacturers, and markets steel valves in a broad range of types, sizes, uses and technologies. During the 1960s, with the help of live-loaded valve technology transferred from AECL, Velan valves were selected for 55 nuclear power plants as well as for all USA nuclear-powered aircraft carriers. In 1992, Velan's worldwide sales were $190 million.

- AECL's self-powered flux detector technology was licenced to Reuter-Stokes, now Image Sensing and Technology. Royalties to AECL have exceeded $200,000.

- Currently, licenses are being concluded covering Spectrasmart, an ultraviolet ambient air analyzer, Comfocheck, an indoor air-quality meter, proprietary catalysts developed for NO_x removal, and a non-cloning amplification technique for DNA which could have far reaching applications in the burgeoning biotechnology market.

- AECL's former Radiochemical Company was privatized and is now Nordion, International, Inc. This company distributes radioisotopes and sells commercial cobalt-60 irradiators world-wide. Nordion supplies approximately 80% of the world's isotope market.

- AECL's former Medical Products Company is currently in the process of being privatized. It operates now as Theratronics, International, and manufactures radiation therapy units.

- AECL Accelerators was created for the development, demonstration and marketing of electron linear accelerators for radiation processing, and the identification of new applications for this technology. AECL has developed the initial product, IMPELA™, a 10 MeV, 50 kW electron-beam accelerator. Two IMPELA™ units were recently sold into a market that is projected to grow in excess of $50 million per year. AECL Accelerators currently employs about 30 staff and has the potential to become a significant business spin-off success for AECL in the near future.

- AECL operated an eddy-current-probe business at the Chalk River Laboratories (CRL), but to grow the business to a profitable level, required partnering. In 1991, Westinghouse Canada Inc bought AECL's eddy current capital assets, established manufacturing facilities in Deep River, and began operation armed with a probe manufacture license and back-to-back probe supply and development agreements with AECL. Currently, the business employs 14 staff, including former AECL employees, and returns approximately $100,000 per year in royalties to AECL.

- Bubble Technology Industries Inc (BTI) was spun-off from AECL in 1988 to manufacture, market, and sell innovative radiation detectors. Patented technology, developed by Dr. H. Ing, while an employee of AECL, provided the original product line for the company. The Chalk River company currently has 15 employees, and Dr. Ing remains the principal shareholder.

- AECL Research set up SENSYS in Ottawa in 1987, to manufacture, market and sell intelligent sensor systems that monitor the health of operating machinery. In 1991, AECL sold SENSYS to a private Canadian Company, GASTOPS.

- EXOTEMP was spun-out from AECL Research in 1990 to manufacture, market, and sell body heating/cooling suits for military and industrial applications. Two former AECL employees licensed the technology from AECL, and during the first year of operation, EXOTEMP received a multi-million dollar order from the British military for cooling suits to be used in the Gulf war. Since that time, the two principals have formed separate companies; EXOTEMP Systems of Kanata and Delta Temax in Pembroke.

Spin-out agreements are currently being negotiated for AECL's neutron radiography business, which provides a key inspection services to the jet engine market, and the production and sale of Integrimet, a precious metal detector portal.

The R&D that underlies this sector also has significant spillover effects to the health and the environmental services and products sectors.

With respect to the health sector, the nuclear S&T funded by the federal government, and performed by AECL, has led to the widespread application of radioisotopes for medical and industrial purposes. Radioisotopes (in particular molybdenum 99) produced at AECL's NRU reactor at Chalk River, Ontario, now supply more than 80% of the world's market for such products. Approximately 30,000 diagnostic procedures are administered each day, most of them in North America, using isotopes produced by AECL. In addition, cobalt 60 is produced in CANDU reactors. This is used for sterilization of medical instruments, other industrial products, and for food irradiation. Total revenues to Canada (most of which are due to exports) from these activities amount to about $100 million annually.

AECL develops technologies for safe disposal of nuclear wastes. In this capacity AECL is developing environmental services and products that are expected to find application in the broader industrial environmental sector. While most of AECL's work is at the R&D stage, commercial applications in non-nuclear sectors are expected to emerge within the next five years.

Fusion

The aim is to develop and refine our unique capabilities in fusion-related technologies, and to use them to gain recognition, and access to international fusion activities, thus obtaining markets for our goods and services and in the longer term, preparing Canada for the advent of fusion power.

The federal government leverages its R&D funding for fusion with the governments of Québec and Ontario and jointly they fund two major fusion projects. In Quebec, the Centre canadien de fusion magnétique (CCFM) operates a medium-sized Tokamak, performing fusion-energy R&D. In Ontario, the Canadian Fusion Fuels Technology Project (CFFTP) manages R&D activities carried out by Canadian industries, universities, and government laboratories, relating to tritium technology, remote handling, and materials development.
The current annual budget for CCFM is $14.4 million. For CFFTP, the budget is $8.8 million per annum, plus an additional $3 million to $4 million received from sales of goods and services. The federal contribution to these activities is $12.8 million per annum of which $8.4 million per annum base funding comes through NRCan's Program on Energy R&D (PERD) and $4.4 million per annum has been provided from various federal sources since 1990-91.

Clients are international fusion projects, foreign R&D laboratories, and Canadian industries. Partners are federal and provincial governments, industries, utilities, and universities. Stakeholders are federal and provincial governments, and federal agencies.

Some 70 smaller companies and about a dozen universities have received contracts from the program. On average, five Canadian scientists/engineers are attached to foreign fusion projects. Sales of goods and services to off-shore customers are currently approximately $3 million per annum. The potential long-term pay-off is, of course, very considerable, once commercial fusion power becomes a reality. The Canadian program, focussing on key niche technologies, is highly regarded by the international fusion community and provides Canada with access to the knowledge and the markets associated with the global effort.

Some of the technologies developed (eg. isotope separation, gas separation, tritium handling and instrumentation, remote handling, fibre optics, communication links, etc.) have applications outside the fusion area. As an example, MPB Technologies of Montreal has successfully applied the optical multiplexing techniques it learned for the Tokamak de Varennes to undersea cable communications resulting in more than $80 million in sales to date.

Uranium

The S&T objectives are: to work with the uranium mining companies to develop effective and affordable close-out technologies and to ensure effluent discharges meet or exceed current and future regulatory standards; to perform R&D which will provide a technical basis for the AECB regulations and for the International Commission on Radiological Protection recommendations; to work with the industry and the regulators to ensure that there is an awareness of newly developing technology that may be applicable to the mining of radioactive ores; and to develop an understanding of the long-term strength characteristics of igneous rocks under elevated temperatures (as will be encountered as stored waste products decay), and the mechanisms of failure which may operate.

Federal S&T funded activities for this sector are performed by NRCan/CANMET. These activities relate largely to providing advice and assessments on the environmental effects of uranium mining. As an example, advice has been provided on the reviews of environmental assessments made in Saskatchewan and at Elliot Lake, Ontario. CANMET also develops technologies related to uranium mining, extraction and environmental protection. Total CANMET S&T expenditures related to the advisory and development activities amount to approximately $0.5 million annually.

The clients are principally private sector mining companies which have responsibilities for developing and closing out mine sites. The federal and provincial Crown are also responsible for many inactive mine sites, and therefore have responsibility for environmental protection and environmentally responsible close-out of these sites.

Partners in addressing these issues are both those with financial responsibility or contribution, and those with technical expertise. They may be private sector, other federal departments, provincial government departments/agencies, Crown corporations and universities.

The stakeholders are principally private sector, federal and provincial departments/agencies, Crown corporations, non-government environmental organizations and also the general public for health and safety considerations.

A significant impact is that the cost of closing-out of mining operations is being substantially reduced by technology development. This can speed approvals of new mining operations. The input of sound science also helps to eliminate spurious arguments as to why mine developments should not proceed, thus helping to maintain jobs and economic development. At the same time improved technologies enhance the degree of environmental protection. Another significant impact is the provision of engineering strength parameters, which are essential for repository design. A third impact is the provision of the national calibration facility for radiation instrumentation.

There are also spillover benefits to the consulting/engineering industry in several areas. For example, mine rehabilitation technology developments involve consulting/engineering companies, and subsequently these companies can sell their service to others, particularly on the international market. CANMET continues to provide key technology advice to a consortium of companies, has sold such services to Germany, achieving income of some $3 million over the last 4 years.

There is benefit to the manufacturers of instrumentation for radiation detection and to the public at large. CANMET's work on radon, for example, is applicable throughout the economy (since radon may be found in residential buildings).

Nature of S&T Opportunities and Strategies

Nuclear (Fission) Energy

The major opportunities stemming from S&T performed by this sector are in exports of CANDU reactors in the next five to ten years, and in building additional reactors in Canada in the next 10 years. A prerequisite for success is to develop advanced products that will meet client expectations and be competitive in the global market place. Another opportunity is to ensure the continued safe, reliable, economical, and environmentally acceptable operation of the current generation of CANDU nuclear power plants. Electricity produced from nuclear power plants will continue to amount to close to 20% of all electricity produced in Canada for the next five to ten years, and, as such, will play an important role in the Canadian economy.

AECL's R&D is also expected to continue to foster spin-off technologies, as described earlier in this report. New opportunities are expected to arise through AECL's nuclear waste management technology, which is expected to find applications in managing other industrial wastes in the future. Neutron-scattering research being conducted by materials scientists at AECL is expected to aid in the discovery of new materials that could have a host of new applications in the future. (Discoveries in materials science during the past few decades, globally, led to the development of fibre optic communication lines, catalytic converters in exhaust systems, lighter and stronger materials in aircraft, boats, automobiles, and recreational equipment such as skis and tennis racquets, drug delivery systems, bio-compatible artificial joints and dental materials, amongst others.)

Fusion

In the international fusion community, the existing and potential markets for fusion-related goods and services are very large, and growing (world spending on fusion R&D is about $2 billion annually). Canada has several unique areas of expertise, and many additional capabilities which, although not unique, are significantly in advance of other competitors. Marketing these skills to foreign fusion projects will create wealth by providing markets for a number of SMEs, and will contribute to the creation of high-technology jobs. If properly exploited, these opportunities could expand for several decades, as fusion energy becomes a practical reality.

In particular, the ITER project is a very attractive near term market. This project is an effort by the US, Japan, Europe and Russia to jointly design, build and operate a prototype fusion test reactor. Now in its engineering design phase, the ITER machine's estimated construction cost is in the order of $6 billion of which about $800 million is in technological areas in which Canada has expertise. A major strategic aim of our fusion program is to ensure Canadian participation in ITER not only for commercial reasons but also to gain access to the world's most advanced fusion technology. This has been achieved through Canada-Euratom agreements.

Uranium

Over the next 5 years, there are opportunities to improve the technology used to mine uranium ores – most particularly in the weak rock envelopes which surround some such ores, and which may be susceptible to ground-fall hazards.

There are also opportunities for the development of the automated remote-mining equipment which might be necessary for the extraction of such ores.

Opportunities also exist to enhance environmental protection measures. That is to encourage application of cost-effective environmental effects monitoring techniques to identify where the real environmental issues exist, and to ensure that technologies exist to minimize the issues. Confidence that these two aspects are well met will ensure speedy approvals of future mining activities and acceptance of close-out technologies.
Over the next 10 years, further verification of the benefits of the new technologies will be needed. The opportunities for new, more environmentally-friendly and cost-effective

mining, extraction and waste handling technologies will continue to be explored.

Federal S&T Capabilities

Nuclear (Fission) Energy

The key capabilities that the federal government, through AECL, has, and will require in the future are:

- Approximately 3,000 scientists, engineers, technicians, management and support staff, working in a highly inter-disciplinary environment, comprise the bulk of the R&D base that underpins the Canadian nuclear industry.

- Specific scientific expertise in the field of nuclear fuel and fuel cycles, nuclear reactor safety, nuclear reactor materials and components, information technology (ergonomics) specialists, heavy water and tritium experts, nuclear waste management experts, materials scientists (using largely neutron scattering techniques), and scientists with expertise in the fields of nuclear physics, chemistry, radiobiology, and environmental science.

- Major facilities, such as a nuclear research reactor with comprehensive in-core test facilities, hot cells for handling highly radioactive materials, isotope processing facilities, computer labs, an underground research laboratory, thermalhydraulic test loops, a low power critical assembly. In addition, AECL makes use of other facilities, such as neutron scattering spectrometers and diffractometers, electron accelerators, a tandem accelerator super conducting cyclotron, and a variety of other experimental and test equipment, machine shops, and support facilities.

Fusion

The key capabilities include: R&D programs in the key fusion technologies carried out by a national team of about 250 scientists,engineers and support staff; demonstrated capability and experience in the design and manufacture of specialized equipment for foreign fusion programs; excellent connections with the international fusion community including membership in the ITER project, giving access to technical information and marketing opportunities. Additional funding will be required in the future as the ITER project goes into its construction phase and in order to keep Canadian fusion facilities, notably the Tokamak de Varennes, relevant to international developments in the field.

Uranium

The key S&T capabilities are very multidisciplinary, particularly to address the multi-faceted environmental issues. However, virtually all the skills required are in the federal government, such as mining, geology, hydrogeology, engineering, chemistry, biology, and mineralogy. In the mining area, for example, CANMET's Mine-Laboratoire, at Val d'Or, can be used for the development of small scale mining equipment. To achieve this, consortia will be formed with the stakeholders, such as equipment manufacturers, the NRC, etc.

Nature and Feasibility of S&T Strategy

Nuclear (Fission) Energy

The main requirement in this sector is a long-term commitment to R&D funding. AECL's R&D funding is currently committed only until 1997 March. R&D programs have generally long-time horizons, require investments in acquiring the right people, developing and training them, and in maintaining, refurbishing and upgrading the experimental infrastructure. Many of AECL's facilities are old. This is a major issue for AECL, as its ability to continue to do its R&D depends on the reliability, capability, and quality of its experimental facilities. In particular, NRU is the only high-flux research reactor remaining in Canada today. It has been in operation for 37 years, and is not likely to continue in operation much beyond the year 2000. AECL, and Canada, need a replacement for the experimental capabilities currently provided by NRU. (AECL is currently developing a concept and will present the case for a new Canadian research reactor in the near future.)

The current capability of AECL to perform world-class R&D does have a critical mass. The critical mass was assured by a government decision in 1990, and it guaranteed R&D funding for seven years. The industry in general was kept viable through the recent reactor sales to Korea and Romania. However, while the nuclear power market, both domestically and internationally, is expected to grow significantly in the future, the timing of such growth is uncertain, and special efforts may be necessary to sustain a critical mass.

The S&T capabilities found within AECL, both in the form of personnel and facilities do not exist anywhere else in Canada. The private sector does not have any substantive R&D capability related to the nuclear technology. The structure of the Canadian nuclear industry is unique in this respect. This centralizing of the R&D capability within one federally funded crown agency has ensured the long term support that is essential for such a technology to develop, and has enabled a critical mass to be sustained. In addition, this centralized capability has allowed a comprehensive multi-disciplinary team to develop, with full integration of all the expertise required to nurture and supply the needs of the nuclear industry.

Fusion

The strategic need is to maintain and enhance Canada's contribution to the international fusion programs, thereby ensuring access to this evolving technology (at minimal cost, highly leveraged), and preparing for Canada's eventual acquisition of fusion power reactors. A national fusion strategy was established in the 1970's after extensive consultation between stakeholders, clients and interested parties from all sectors. A major feature of Canada's strategy is to concentrate efforts in a few areas of domestic expertise of interest to foreign programs. In this way we have obtained access to global fusion technology by making excellent contributions to the world effort. The National Fusion Program (NFP) was established to further develop, integrate and coordinate the strategy; the NFP was first managed by NRC and was then transferred to AECL where it remains. Since we cannot afford to fund a full domestic fusion program, international collaboration is essential to our strategy and thus, we have developed excellent working relationships with the world's major fusion programs. The trend of the last decade to develop an even higher degree of international fusion collaboration, as exemplified by ITER, has acted very much in Canada's favour. Another notable feature of our domestic strategy has been the federal partnerships with Ontario Hydro and Hydro Quebec both to share costs and to ensure the ultimate relevance of the technology to power generation.

The program requires a long-term commitment to stable funding, to allow effective execution of our strategy in fusion. In particular, the commitments by the program to international projects and agreements must be recognized and supported if we are to remain credible partners. In recent years, the level of fusion program funding has received intense examination by officials and ministers on many occasions. Strong support has been given to the annual funding level of $12.8 million, set in 1990 and largely matched by Ontario and Quebec, required to maintain Canada's participation in ITER. NRCan's PERD program provides a base annual funding level of $8.4 million for fusion and since 1990/91 various ad hoc measures have been employed to maintain the necessary level. A resolution of this problem would greatly contribute to program stability.

The present level of capabilities forms a critical mass for the current program. In the short term significant expansion, driven by ITER, is likely to occur in areas such as tritium, remote handling and reactor construction-type activities. In these areas there are significant capabilities outside the fusion program which could be harnessed to meet an increased demand. Training of graduate students is carried out throughout the fusion program (about 20 at any given time).

Fusion R&D requires specialized and unique facilities, and equally specialized personnel. As with all forefront experimental devices, the Tokamak de Varennes requires continual improvement and upgrading over its lifetime in order to maintain its technical relevance. It is estimated that the current machine configuration will be capable of producing leading-edge results for only a few more years and thus, a major upgrade to the machine, called TdeV-M, is now in the planning stage. TdeV-M will build on many of the existing components of TdeV rather than necessitating the construction of a whole new machine. Current estimates are that TdeV-M will require a one-time special capital injection of $10 million over a three-year period.

Fusion also involves working with radioactive materials (tritium) and experimental apparatus that generates nuclear radiation. This requires that some of the work be conducted in specially licensed facilities – most of these are in government or utility laboratories. The facilities of industry, sometimes very specialized manufacturing facilities, and universities have also proved very valuable in carrying out other program tasks. The remote manipulation laboratories of Spar, the ceramic fabrication facilities of Ceramics Kingston and the dual beam accelerator at the University of Toronto's Institute for Aerospace Studies are examples of facilities that permit a high level of performance for Canada in international fusion activities.

Uranium

The key consideration is that there needs to be an overall industrial strategy for Canada. At a lower level, this would result in a strategy for the mining, equipment manufacturing and environmental sectors. As a national thrust, Canada could aim for the development of an indigenous industry for the manufacturing of small-scale high-technology mining equipment.

Thus, as well as developing new technologies to meet industry needs, a key federal role is to bring together stakeholders, to identify issues, prioritize actions and coordinate activities and funding to encourage resolution of issues. Sharing the concerns of the stakeholders, will encourage consensus in developing and applying new technologies, i.e. the effectiveness will be much increased.

The critical masses exist in different parts of government and other groups across Canada for addressing issues in the nuclear industry. In CANMET, there is expertise to resolve problems and develop new technologies related to uranium mining, extraction and related environmental protection. Expertise also exists on these subjects with some private sector engineering, environmental and research companies. Hence CANMET tends to become involved only when niche expertise is needed which is not available from the private sector, or when internal government reviews require CANMET's expertise.

The expertise of CANMET is unique in certain niche areas; it possesses equipment and facilities which are not duplicated elsewhere in Canada. For example, radiation calibration equipment at Elliot Lake, rock testing equipment in Bells Corners and Val d'Or, and mineralogical identification instrumentation in Ottawa. Other examples are in mineralogical identifications, whether of ore or fabricated fuel, or in chemical analyses where no other Canadian source of umpire analyses of uranium concentrates exist. The position of the federal government is also unique in being able to bring various stakeholders together to jointly discuss and resolve problems.

Expertise, including research capabilities, exists on uranium refining, conversion and fuel fabrication with the Canadian companies that specialize in these activities.

S&T Strategies

Nuclear (Fission) Energy

A well articulated government policy that supports the continuing use and future expansion of nuclear electricity generation, based on its contribution to sustainable wealth and job creation, is a key factor in gaining public and client confidence in the CANDU technology, both at home and abroad. Foreign clients, in particular, are sensitive to government policy and long term support in this regard. To realize the full and sustainable benefits of the nuclear energy sector, the following strategies should be pursued:

- Canada's science policy must include the nuclear energy option as a key element. Support of the nuclear option includes a long-term commitment to funding of R&D to maintain Canada's nuclear research infrastructure and a competitive product and industry.

- Substantial investment is required to replace the R&D capability currently provided by the NRU research reactor (now 37 years old) in the next few years. This is a critical element of the nuclear research infrastructure. Without this investment, the Canadian nuclear industry will not be able to adequately support currently operating CANDUs, will not attract young scientists and engineers to advance the technology, and will, therefore, not be viable in the long term.

- If the concept for disposal of nuclear fuel waste is found acceptable by the Federal

Environmental Assessment Review Process, the government should maintain a bridging R&D program in the period between the environmental review and the time at which disposal is required.

- The federal government should continue to seek funding assistance for the nuclear R&D programs from provincial utilities and industrial stakeholders. This will leverage the federal government's direct funding.

Fusion

Realization of the S&T opportunities will require continued stable funding at the present level with provision for increased funding to upgrade facilities and to pursue the opportunities presented by ITER construction. This in turn will require a supportive policy environment that recognizes the development of fusion power as a national objective and priority to meet future energy requirements with minimal environmental impact.

Uranium

Aspects of great importance in promoting uranium industry S&T activities are:

- Clear regulatory requirements so that consensus is easily achieved on needs and that there is conviction that expenditures will not be wasted by changing of the rules.

- A climate for investment in Canada which encourages economic development so there are clear opportunities to apply new technologies.

- Regulatory activities which are completed in a timely manner so as not to hamper Canadian industry related to international competitors.

- An increased awareness and understanding by the public of the net benefits of applied science.

- Encouraging the transfer of technology from the basic research stage to application; at times this may require financial incentives.

CANMET has an excellent appreciation of all these points and already works closely with all parties involved. We would therefore recommend that a multi-partite consortium be formed for the purpose of driving a national thrust. NRCan is well positioned to coordinate this.

Other Considerations

Nuclear (Fission) Energy

As stated earlier, nuclear energy is a clean form of energy and burns a fuel that has no other significant uses and is abundant in Canada. The amount of material burnt is less than for any other energy source. Nuclear electricity generation emits none of the acid and greenhouse gases that accompany fossil fuel burning. The nuclear wastes are very small in quantity, are readily and safely stored for many decades, and, when necessary, can be disposed of permanently with technologies that exist today. In spite of these technical solutions, concerns over this technology continue.

If necessary, the spent fuel can be recycled to increase the fuel resources manyfold. Thus, nuclear energy use can preserve Canada's and the world's other, i.e. fossil, energy resources for other applications, and stretch their availability for longer periods of time. This makes nuclear energy a truly sustainable and environmentally acceptable form of energy for centuries to come.

Nuclear power plants can be located practically anywhere. Transportation of fuel is not a factor, being of such small quantity. As such, the location of nuclear power plants can be strategically chosen to foster regional economic development, given that the overall economic and social factors are optimized in the process.

Practically all R&D facilities related to this sector are currently located at two AECL sites, at Chalk River in Ontario and at Whiteshell in Manitoba. The nearby communities depend greatly on the economic activities brought into their areas by virtue of the locations of these labs. Spin-off technologies, as is the case for most high-tech enterprises, are quite mobile and easily located anywhere in Canada. Access to other R&D infrastructures or knowledge intensive industries are, however, an inducement for co-location.

The CANDU nuclear power system is a uniquely Canadian technology. However, it developed through strong collaboration, particularly in the early years, with the U.K. and the U.S. Strong international collaboration exists at all levels to this day, except at the commercial exploitation stage, where AECL competes fiercely with its U.S., French, German, and, more recently, Japanese competitors.

AECL both performs and participates in several important international R&D programs, most notably in nuclear fuel waste management, reactor safety, advanced fuel cycle, and general reactor concepts development work. AECL has technical cooperation agreements with numerous countries, including the U.S., Japan, the U.K., Korea, Argentina, the Netherlands, Germany, France, Hungary, Egypt, Russia, and others, and is a major participant in the scientific activities of the International Atomic Energy Agency and the OECD. Through AECL, the Canadian government is currently assisting the Former Soviet Union with upgrading the safety of the Chernobyl type reactor.

Fusion

Fusion energy has the potential capability of providing an abundant source of electricity from an essentially inexhaustible fuel source, while producing no atmospheric pollution, and generating only modest amounts of low-level, easily managed radioactive wastes. The overall environmental impact would be significantly lower than either fossil, or even fission energy sources.

The two major projects in the Canadian fusion program operate in full partnership with the provincial governments of, respectively, Quebec and Ontario, and contract goods and services from many SMEs in those provinces. CCFM is the largest scientific project in Quebec, with a cumulative capital investment of about $65 million and an annual budget of $14.4 million. The economic impact of CFFTP is calculated to be in the order of $12 million to $13 million per annum including some $3 million of offshore funds. These benefits will continue, and expand with the program.

Fusion is firmly established as an international activity, and extensive linkages and networks of communication are in place. Many of the developed countries have fusion programs, and participate in fusion activities sponsored by the International Energy Agency (IEA) of the OECD, and the International Atomic Energy Agency (IAEA) of the United Nations. The four major fusion powers: Japan, USA, Russia and the EU collaborate in the ITER Project and Canada participates through an agreement with the EU. There are many international conferences, providing communication opportunities for both major and minor players, and, in addition, many specialized meetings, symposia and workshops. Canada participates in many of those meetings, chairs the key IAEA fusion committee, is a signatory to five IEA fusion agreements, and has bi-lateral fusion agreements with Japan, the EU and the U.S. International collaboration is essential to Canada's fusion strategy and thus, our intention is to fulfil, maintain, strengthen and extend these relationships in the future with the ultimate aim of laying the foundations for strategic alliances to construct fusion reactors and their components both in Canada and abroad.

Uranium

The nuclear industry in the former Soviet Union and Eastern European countries is one of the most significant examples of the dependence of environmental sustainability on economic development. Where there was insufficient economic development, there were insufficient funds to protect or sustain the environment effectively.

Canadians have very high expectations for lifestyle and safe working environments. There are health and safety considerations in working in the nuclear industries, and in the management of wastes. CANMET contributes greatly to the attainment of the health and safety objectives.

Canada's uranium mining and fuel production activities are generally located far from urban centres. Many of CANMET's activities in support of this industry are also far from urban centres, e.g. Elliot Lake and Val d'Or. There is, consequently, substantial support for regional economies, and further regional development would occur with initiatives mentioned above, particularly in those communities considered as mining centres.

Incoming international technologies have had little effect on the uranium production processes in Canada. This country has been a leader in these technologies since the late 1940s when innovative Canadian developments from the Mines Branch (CANMET's forerunner) were put in place at Port Radium, NWT. As the world's largest uranium producer, Canada continues to be a leader in technology development, particularly in environmental protection technologies such as control of acid mine drainage and ammonia. This is developing opportunities for off shore sales.

In the development of highly-automated small-scale mining equipment, of the type which could be used in manless mining in hazardous locations, there is an opportunity for Canada to initiate the effort and be the world leader.

Indicators of Federal S&T Impact and Success

Nuclear (Fission) Energy

The most important indicator, in the next ten years, will be the continued competitiveness of the CANDU technology internationally, and, hence, success in getting export reactor sales. AECL is one of five major nuclear power plant suppliers globally (the others being Westinghouse, General Electric, NPI – the Framatome-Siemens consortium, and Asea

Brown Boveri-Combustion Engineering). A good measure of success will be AECL's share of the new nuclear power market. AECL aims to capture one quarter of this new market. Continued R&D support is essential to advance the technology and keep it competitive in light of the competitors' continued advancements. Other potential indicators will be:

- The continuing good performance of existing CANDU reactors in Canada and abroad.

- A progressively increasing share of R&D funding by the utilities and the private sector.

- The growth of the nuclear industry, in terms of contribution to Canada's GDP, and in the number of jobs in knowledge-based industries.

- The creation of small, entrepreneurial businesses from spin-off technologies.

- Continued reductions in the emissions of acid and greenhouse gases, which would, in part, be due to continued or increased use of nuclear power.

Canada participates in a number of pre-competitive international science programs, in which Canada is mainly a beneficiary of basic nuclear science (e.g. CERN). Canada is at risk of not contributing its share to international science. A further measure of success of Canadian S&T policy would be increased levels of contributions in this area and an enhanced international S&T image for Canada.

Fusion

Indications of success would include: increased sales of goods and services to off-shore markets; increased opportunities for attachment of Canadian personnel to foreign projects; extension of the communication net through new linkages and agreements; increased support and funding for the federal-provincial joint projects.

Uranium

Indicators of future success of the nuclear industry will be the economic well-being of the Canadian uranium industry, particularly judged from reduced costs for uranium production.

Other important indicators will be reduced environmental impacts, reduced time and frequency of environmental assessments, decreased frequencies of accidents at uranium mines, public acceptance of waste containment procedures for mine, industrial and reactor wastes, and reduced radon hazards for the public in general. CANMET will play a major role in the development and public acceptance of many of the advances which will achieve gains in these areas.

Synopsis: Nuclear Energy

Importance for Wealth and Job Creation

- The Canadian nuclear industry generates electricity and other goods and services valued at about $6 billion annually (based on estimates for 1993).

- Direct employment in the nuclear industry in 1992 is estimated at about 30,000 jobs. A minimum of 10,000 jobs in other sectors indirectly depend on the nuclear industry. As well, this industry supports about 60,000 induced jobs.

- The federal government receives approximately $700 million annually from the nuclear industry in the form of income and sales taxes.

- Canada's nuclear industry had a trade surplus of approximately $500 million in 1991, only one of two high-tech sectors to do so.

- Ontario Hydro estimates that, from 1965 to 1989, nuclear energy has saved the Canadian economy approximately $17 billion in foreign exchange (i.e. largely foregone coal or oil imports.)

- Canada is the world's leading supplier of uranium and accounted for 28% of world output in 1993, with an estimated value of some $500 million.

- The generation of electricity burns very small amounts of a material which has no other significant uses.

- Nuclear power generates less waste than any other energy source. It emits no acid gases, no greenhouse gases, and no particulates.

- Spent fuel wastes are stored at the power generating sites and costs have been internalized. In addition, the fuel wastes can be recycled. Concepts for permanent disposal of nuclear fuel wastes are available. Nuclear energy is unique in this regard.

- Nuclear energy is an alternative to hydrocarbons for the long term.

Future S&T Strategy

- Canada's science policy must include the nuclear energy option as a key element. Support of the nuclear option includes a long-term commitment to funding of R&D to maintain Canada's nuclear research infrastructure.

- Substantial investment is required to replace the R&D capability currently provided by the NRU research reactor (now 37 years old) in the next few years. This is a critical element of the nuclear research infrastructure.

- If the concept for disposal of nuclear fuel waste is found acceptable by the Federal Environmental Assessment Review Process, the government should maintain a bridging R&D program in the period between the environmental review and the time at which disposal is required

- The federal government should continue to seek funding assistance for the nuclear R&D programs from provincial utilities and industrial stakeholders. This will leverage the federal government's direct funding.

- Canada's contribution to the international fusion programs must be maintained, thereby ensuring access to this evolving technology and preparing for Canada's eventual acquisition of fusion power reactors.

- The government must clearly articulate its strategy with respect to the mining and environmental sectors. In particular, clear regulatory requirements must be set, based on consensus, to avoid unnecessary costs resulting from constant changes in these requirements.

- There is an opportunity for Canada to initiate effort and become a world leader in highly automated small-scale mining equipment, not only for uranium mining but also for other hazardous locations.

Electricity Sector Profile

Sector Overview

[This is a general sector profile. Details of nuclear, coal, renewables and oil and gas generation are covered in other chapters of this report]

Introduction

Electricity use has become synonymous with industrial growth. In industrial countries electricity demand growth has closely tracked economic growth for decades. Today's advanced information society, computer-aided design and manufacturing techniques and lifestyle changes all require high quality and reliable electricity supply. The energy needs of these activities cannot be met from sources other than electricity. Electricity is thus vital to almost every aspect of Canadian society and to the Canadian economy, and its role will continue to expand over the next 10 years.

Electric power is unique among other forms of energy supply. It is a secondary energy source obtained from the conversion of other primary energy inputs. In Canada, the principal sources of central electricity generation include hydropower, natural gas, oil, coal and nuclear power. There is a non-utility power generation component that uses small scale hydro, oil, gas, and renewable energy sources.

The electrical equipment manufacturing sector produces a variety of products, including equipment for generating stations, power transmission and distribution equipment, electric motors, capacitors and transformers. It also produces power conversion equipment, alternate generating equipment (wind, small hydro) advanced batteries and fuel cells. Electrical utilities comprise the principal market for electrical products.

Key Dynamics of the Industry

The electric power industry is a significant component of the Canadian economy, employing almost 95,000 people directly and generating revenue of about $24.5 billion in 1992. Of this total, about $708 million came from export sales. The industry is the largest investor in the energy sector, with capital expenditures of $12 billion in 1992. The assets of the industry were about $138 billion accounting for about 7.5% of the capital stock of the Canadian economy, excluding the residential sector. Since 1960, electricity consumption in Canada has grown at an average annual rate of 4.8%, and currently stands at 471 terawatt hours (TWh). Electricity's share of total secondary demand has grown from 11% to 25% over the last 30 years. Demands for electricity in the residential and commercial sectors have been increasing more rapidly than in the industrial sector over the past two decades. However, the industrial sector still accounts for almost 40% of sectoral demand.

Canada imported 6.2 TWh and exported 24.5 TWh. Quebec, British Columbia, Manitoba, New Brunswick and Ontario were the main electricity exporters. Ontario, Quebec and British Columbia were the principal destinations for U.S. electricity imports. In total, Canadian revenues from electricity exports were $708 million in 1992, while expenditures on imports were $84 million, yielding a net trade surplus of $624 million.

Interprovincial trade in electricity amounted to approximately 41 TWh in 1992. The transfer of electricity from Newfoundland to Quebec accounted for over 60% of this figure.

The total length of Canadian bulk electricity transmission and distribution is 154,604 kilometres. Thirty-two per cent of this is in the 110 kV to 149 kV range. An additional 25% is in the 200 kV to 299 kV range. Newfoundland and Québec are the only provinces with transmissions line over 600 kV. To facilitate exchanges between provinces, and to enhance reliability, there are 36 major provincial interconnections. With such a long distance transmission reliability of service and systems maintenance are key factors.

The electrical equipment manufacturing industry employs about 80,000 people and ships about $7 billion in products annually, $2 billion of which are exports. Manufacturers fall into two categories: small Canadian owned firms producing specialized products for niche markets; and larger, foreign owned, multinationals. The most successful exporting subsidiaries of foreign multinational have world product mandates. Occasionally exporting by the subsidiary is limited to Canadian financed projects.

The cancellation of large domestic power projects and slow economic growth, have affected the industry. As a result, exports have become increasingly important for the survival of the industry.

The global electrical equipment industry will continue operating in two distinct growth environments: mature markets (Canada, US, Europe and Japan); and the developing world. These markets have different characteristics. The former has mature indigenous electrical industries and surplus generating capacity. The developing markets will continue to import electrical equipment particularly in larger generation and transmission equipment to support their economic growth. For the balance of the decade an increase of over 30% in electricity supply is expected, requiring about $3 trillion in electrical equipment. The largest potential market is in Asia.

Electricity Sector Profile

Future Generation of Wealth

Electricity generation and transmission and distribution contributes significantly to wealth generation and sustainable development, and will continue to do so to an even greater degree in the future. Electricity is necessary for a wide variety of applications from electric motors, sensors and electronic controllers to electrolytic cells and a host of other electrotechnologies. Efficient production of electricity keeps the price of electricity, and therefore the cost of goods down, and permits the wider use of electrotechnologies. Electrotechnologies can reduce waste in manufacturing, and permit better process control resulting in higher quality products. Electricity generation in centralized systems permits economies of scale, better systems optimization and localization of wastes and emissions. control equipment, and engineered substations.

Electricity exports account for 5% to 10% of Canada's total generation. Principal markets are the New England states, New York state, the upper Midwest, the Pacific northwest and California. In 1992, Canadian utilities exported 245 TWh of electricity. Utilities are forecasting a modest growth in exports to 30 TWh by the year 2000. Long-term access to U.S. markets allows economies of scale in power generation, and increases the security of power supply by permitting mutual emergency backup. Such access also takes advantage of the diversity of the loads in Canada and the United States. Moreover, it provides a very profitable market for Canada's abundant and low cost energy resources.
Projections for electricity demand for the 10-15 years show slow growth under a "business as usual scenario". However, international environmental agreements and legislation could result in increased electricity requirements if there is switching to more electrotechnologies, advanced manufacturing processes and greater electrification of transport to meet targets.

In the equipment manufacturing industry, major trends expected are: i) increased requirements for equipment to replace and refurbish older power plants and systems; ii) growing demand for more sophisticated technologies with emphasis on efficiency and demand-side management (DSM); iii) substantial demands for alternative energy equipment especially in cogeneration, small hydro, wind and solar; iv) increased manufacturing capability in the developing countries; v) gradual harmonization of electrical equipment standard worldwide; and vi) ferocious global competition and continued industry restructuring.

Although product quality and new technologies are Canada's major strengths, Canadian firms face many challenges in adapting to the global trends. Skilled tradesmen and technologists are scarce. Tariff and non-tariff barriers remain impediments, and "Buy America" policies are still a barrier to the U.S. utility market. Markets in Western Europe and Japan remain largely closed. Many firms are small and undercapitalized, consequently, they lack the funds to do extensive R&D. Project financing is a constraint, and many foreign governments support their firms with concessional financing.

The greatest potential new markets for Canada are developing countries in Asia, South America and the Middle East. Canadian suppliers can capture a share of the $25 billion world market expected during the 1993 - 2000 period. Canada's largest market is still the USA, and NAFTA should expand our exports to the US and open the Mexican market.

International agreements on the environment could result in greater demands for electrotechnologies and equipment for alternative generation, as well as for the refurbishing of existing generation facilities with more efficient technologies.

Sustainable Development Issues

There are four major issues related to sustainable development: i) increasing the efficiency of electricity use; ii) optimizing the efficiency of existing power plants, transmission and distribution systems; iii) minimizing the requirements for new generating plant through demand side management; and iv) reducing pollutants from generation.

Canada is among the countries with the highest electricity intensity (electricity consumption per unit of GDP). This is as result of several factors including our cold climate and our long distances and our electricity intensive industries. Since the first oil embargo of 1973, a shift to electricity took place in all sectors of the economy. Utilities needed to find ways to meet growing demand for electricity. They did this by maximizing the efficiency of existing operations, and reducing the demand for new large generating plants through demand-side management actions.

Alternative generation (mostly non-utility) technologies (small hydro, cogeneration, wind and gas turbines) can be used to further minimize the requirements for new large generating plants. These sources could play an increasing role in the next decade or two.

About 60% of the energy produced in coal combustion using existing technology is of waste heat. Flue gases include several chemicals including: sulphur and nitrogen oxides (which cause acid rain); hydrocarbons (which cause depletion of the ozone layer); and carbon dioxide (which is a main contributor to the greenhouse effect). Other by-products of coal combustion include contaminated solid wastes and process waters. Oil-fired generation emits carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides and hydrocarbons. Electricity generation from natural gas produces carbon dioxide (hydrogen sulphide having been removed before combustion). The environmental impacts from dam construction for hydro power include: local climate modification; fish; wildlife; and vegetation destruction. Up-stream water levels and flow are also affected, as are nutrient content and water temperature. Nuclear generation does not produce any significant emissions but safety and the management of radioactive wastes are public concerns. Mine tailings, produced from uranium mining, milling and fabrication, contain residual amounts of uranium, thorium and radon. which must be strictly controlled to prevent surface and ground water contamination. Some sites are of considerable concern.

Increased electrification, using modern, efficient equipment, will reduce waste materials, reduce emissions at point of application and permit centralized pollutant control at the generation source thus promoting sustainable development.

Characteristics of Innovation in the Sector

Canada holds a significant place in the world's electric power industry as result of its innovative capability. Canada has developed an international reputation as a reliable supplier of high quality products that incorporate the most advanced technologies. Specific product areas of expertise include hydrogenerators and turbines; power plant components; boilers; medium and large power transformers; capacitors; wire and cable; protection equipment; control equipment; engineered substations; and data acquisition equipment.

R&D has allowed many firms to become competitive in these areas. The utilities of Ontario, Quebec and British Columbia have large well-equipped laboratories with world class testing facilities, and the equipment industry works with them to develop advanced products. However, they could transfer more of their technology to smaller Canadian manufacturers. The multinationals have their own laboratories but these are located outside Canada. The exceptions are in areas where their Canadian subsidiaries have developed world product mandates. Some of the R&D for the development of these products has been cost-shared with the federal and provincial governments.

The large hydro industry is well established, Canada being the largest hydropower producer in the world. The industry is multinational, does most its research itself, and has a good record of innovation. Governments have supported technology development where the parent firm is willing to grant a world product mandate to its Canadian subsidiary but some firms have world product mandates even where there was no government support.

Canada is also considered as one of the most innovative countries in the field of demand side management, because of the interest of its large utilities in controlling large capital expenditure on new generation and in dealing with environmental concerns.

Canada has the largest power transmission system in the world. Canadian utilities have had to develop world leadership to ensure reliable electric service during Canada's long severe winters. Research on transmission and distribution is done mainly by Ontario Hydro, Hydro-Quebec and B.C. Power, which have large well-equipped world-class facilities and expertise. Manitoba Hydro, with federal assistance, has developed a centre in high voltage DC transmission. These utilities cover a wide variety of areas including: extra-high voltage AC or high voltage DC transmission; power transformers and distribution transformers; capacitors; sub-stations; super conductivity; and possible health effects from power lines.

Potential for S&T Advancement to Support Wealth Creation

In the hydro power sector, new approaches using computational fluid dynamics and modern electronics can help to increase the efficiency of large scale hydrogenerators, turbines and controllers. Much of the new modelling and design efforts in these fields is being done by the supply industry. Canadian companies may acquire world product mandates from their parent firms.

Continued S&T on transmission and distribution can contribute to wealth generation by increasing the efficiency of transmission and distribution through reduction of losses, thus increasing the amount and quality of electricity and reducing demand for new generation. S&T on transmission and distribution can also contribute to wealth through the sale of resulting goods and services. Areas for S&T include: ultra high voltage AC transmission; protectors; capacitors, transformers; power systems dynamics; conductor dynamics; power cables; and insulators.

Canada already has a solid international reputation for innovative products that it can build on in the future. There is a tremendous potential for this sector to support more wealth creation through the export of technologies to: refurbish existing plants; to supply small hydro turbines and small wind generators; power electronics, advanced batteries; and in the longer term, advanced fuel cells and superconducting wires to name but a few.

Electricity Sector Profile

Strategic Needs

Canadians need to develop more collaborative approaches to bidding on large and small power projects in developing countries. Companies should be encouraged to form more strategic alliances, with both Canadian and foreign (including foreign) partners, and to join CASEP (Canadian Power Systems Export Promotion).

Better approaches to transfer technologies developed by the utilities are necessary. The major utilities have developed a considerable knowledge base. They could expand efforts to transfer knowledge to SMEs.

The development of the capability to put together complete generating retrofit packages to refurbish power plants at home and in the developing world market would see major export benefits. Canada has the technology base and the expertise. Suppliers do, however, need assistance in marketing, selling and adapting their products and services to local foreign conditions.

Canada is a leader in demand side management technologies. Canadian utilities need to continue to develop innovative DSM approaches in such areas as telemetering, time of day pricing, demand reduction and load shifting technologies.

In addition, there is a need for more R&D for environmental protection associated with electric power generation, including environmental impacts of all forms of electricity generation and options to prevent or remediate adverse impacts.

Canadian SMEs have the potential to capture a significant part of the international market but require the continuing availability of skilled tradesmen and technologists, assistance with market research and assistance in the engineering development of technology. Companies must become proactive in considering potential new markets, and forge strategic alliances both with domestic and international partners. They need to form manufacturing clusters with parts suppliers to address international markets, and introduce advanced manufacturing technologies to continue to make quality products at competitive prices. International standardization and harmonization will also help these SMEs find new markets.

There should be a major new thrust in electrotechnologies and power electronics to address future national needs and the international market. This would likely grow considerably in the wake of environment concerns and sustainable development.

Ability of Industry to Capture Benefits of Technology Advancements

The Canadian electricity sector including equipment manufacturers is an established industry and has the demonstrated capability to capture the benefits of technology advancements. This will continue if the strategic needs identified above are met.

Electricity Sector Profile

Assessment of Federal S&T Capabilities

Overview

While the primary responsibility for electricity supply falls within provincial jurisdiction, federal involvement in the electricity sector has been extensive. Federal jurisdiction includes nuclear power facilities, interprovincial and international trade and transmission. The federal government is responsible for environmental assessments of electricity projects impacting areas of federal responsibility including all hydroelectric projects, nuclear projects, transmission lines crossing aboriginal lands or international boundaries, and thermal generating stations with port facilities. There is joint federal responsibility with regard to atmospheric emissions from thermal generating stations.

In addition, the federal government has a role in ensuring the development of the knowledge base for longer term technologies for electricity generation and efficient end use.

Thus the federal role in electricity S&T is related to nuclear power, environment, efficient use of electricity, longer term generating options and fundamental research.

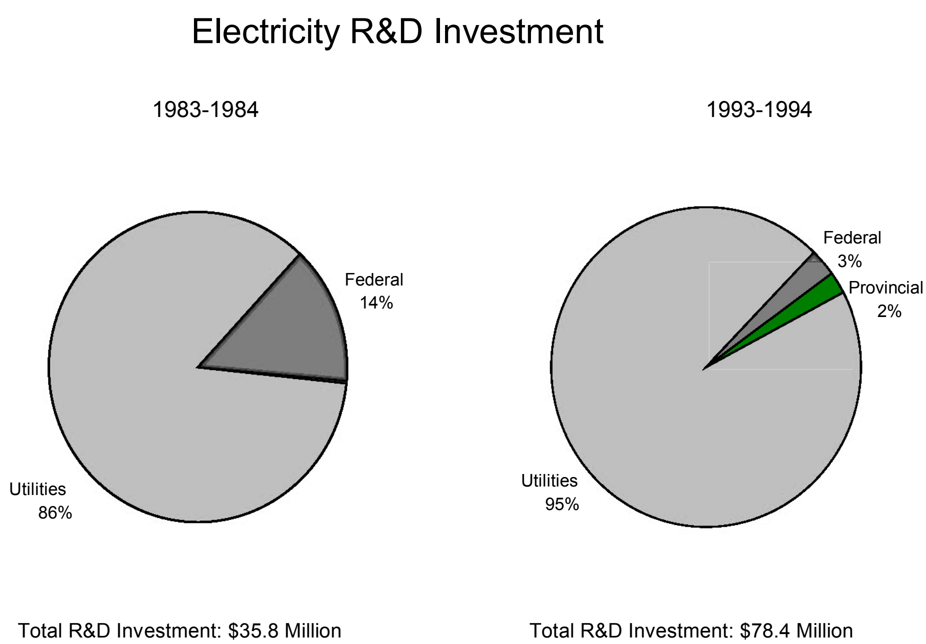
R&D Investment Trends

In 1983 a total of $35.8 million dollars was invested in electricity R&D. The percentage contribution of each partner is shown in Figure 18. Of this $35.8 million, the utilities contributed $30.8 million. The federal government's investment in this area totalled $5 million, the bulk of which was directed through the Canadian Electrical Association. The federal investment ensures that the smaller utilities gain access to the results generated by R&D in this area.

The R&D investment supported research for the transmission and distribution of electricity. It also supported activities in the efficient use of electricity.

Since 1983, investment in electricity has increased dramatically. By 1993 total investment was $78.4 million, an increase of 119%. The federal government's share declined to $2.5 million, 50% of its 1983 level. The utilities were very active and as a result their level of investment into R&D activities for electricity increased to $74.6 million, an increase of 142% over 1983 levels. The provinces became involved in this research contributing $1.3 million while industry remained inactive. The level of investment by utilities have been decreasing somewhat since 1993.

Figure 18



Current Activities

The federal S&T complements the work being done by utilities and industry, working in areas where the utilities are unwilling or unable to fund alone, but which are strategically important for the national interest. Such areas include: environment; electrical measurement; niche market technologies; and long-term/high risk technologies. The prime focus of these efforts are continuing wealth generation and sustainability.

The federal government performs and funds electricity R&D in several departments. The major federal program is PERD. NRCan, through PERD funds, contracts and contributes work on: geotechnics and large hydro developments; DSM; efficient motors; power electronics; electrical drying technologies; fuel cells; and other electrotechnologies. NRCan provides a contribution to the CEA, which the CEA cost-shares, to support work of common interest to all electricity utilities. NRCan also supports research on permafrost and ice cores, and terrestrial ecosystems in relation to climate change.

National Research Council performs work on electrical measurements and environmental chemistry and may fund equipment development through IRAP.

NSERC funds research, through the Energy Strategic Grants program, in areas such as electrical networks optimization and fuel cells.

EC funds S&T on environmental impacts of electricity generation including water quality, environmental baseline studies and impacts of large hydro development, and, carbon-climate coupled modelling in relation to climate change.

F&O funds research on hydro-electric development impacts on aquatic life, biological production and the cumulative effects on large geographic regions, and on carbon dioxide flux, ocean uptake and ocean biological capacity to sequester carbon dioxide in relation to climate change.

The impacts of previous and present federal activities include: development and sales of equipment (nationally and internationally) by the private sector based on federal funding assistance, federal expert advice for environmental impact assessments and more efficient use of electricity.

Federal investment has resulted in a substantial contribution to the present Canadian knowledge base for environmental assessment of hydro development.

Federal investment in specific projects in large hydro has permitted subsidiaries of multinationals to gain a world product mandates from their parent for particular technologies. Hydrogenerators is a particular example.

Federal funding and advice to Canadian firms from programs like IRAP and IERD for proprietary technology development have resulted in a wide range of technologies (mostly related to electricity use) being marketed domestically and internationally. For example, the following technologies are now being developed with NRCan's IERD support: motor controllers; power factor controllers; hydrogenerators and turbines; impulse drying; and radio frequency drying. When fully implemented, these technologies are projected to generate about $700 million in sales (nationally and internationally) per annum.

S&T Opportunities

The S&T opportunities in the equipment sector, which industry and the federal government departments can support to enhance wealth creation, are in development of electrotechnology niches. Areas include RF and microwave heating and drying; impulse drying; environmental electrotechnologies (electro-coagulation and membrane separation); and power electronics.

The key S&T expertise which the federal government has in relation to the electricity sector is in environmental science (EC), climate change (NRCan, EC, F&O, AgCan) waste water technology (EC), environmental chemistry (EC, NRC), atmospheric emissions (NRCan, EC, NRC) and electrical measurements and superconductivity (NRC). Some of this expertise is unique in Canada.

S&T Strategy

The federal government's role in electricity is in the development of the knowledge base related to environmental impacts and mitigation, climate change and standards and support of niche technology development in large hydro and electrical equipment with SMEs and multinationals (with world product mandates).

The federal government does not require additional capability in relation to generation, transmission and distribution. The utilities of Québec, Ontario and British Columbia have large well-equipped world class laboratories which perform considerable S&T on transmission and distribution, environment, and electrotechnologies. Other utilities such as NB Power also perform some S&T. Manitoba Hydro, with federal support, has developed capability in high voltage DC transmission and operates the HVDC. Canadian utilities are world leaders in: medium to large power transformers; extra high voltage AC and high voltage DC transmission; medium and high voltage capacitors; protection equipment; control equipment; and engineered substations.

However, there is need to extend the environmental knowledge base to deal with generic, cumulative and global impacts of electricity. Such knowledge will allow us to proceed with developments in a sensible way, with a good understanding of the impacts and how to mitigate them.

The federal S&T capabilities complement those of the major utilities and act as knowledge base for the smaller utilities. In addition, the federal government provides an S&T contribution to the Canadian Electrical Association (CEA) for work on technologies of interest to all Canadian utilities again with a primary benefit for the smaller utilities.

Electrotechnologies such as RF, microwave, IR, electron beam, membrane separations, robotics and magnaforming are major future end-use opportunities for wealth creation. They find application in not only the electrical sector but in a variety of environmental applications, manufacturing industries, and energy efficiency. The federal government could play a role in organizing a major thrust in this area, building on Canadian expertise in the utilities and in SMEs and on Canada's reputation for high quality products.

Other Considerations

Electricity is vital to almost every aspect of Canadian society. It is the only source of energy which can power advanced information networks, computer-aided design and manufacturing, electronic controls of almost every industrial process, and electrotechnologies.

Electricity is important for wealth creation and for sustainability. Electricity is easy to control, produces no waste at the point of use, and reduces material waste in manufacturing. As well, it permits the application of robotics, the application of electrolytic processes and sophisticated environmental technologies. Electricity may also have a major part to play in electrified transportation to reduce urban pollution. A fundamental role for high quality and reliable electricity will be the telecommunications sector.

Canadian utilities and the CEA have considerable collaboration with EPRI in the USA. This will likely continue. Canadian utilities participate in IEA studies on electricity and have membership on the IEA Expert Group on electricity. Canada participates in the IEA R&D agreements on superconductivity (Ontario Hydro and Hydro-Québec), electric vehicles and fuel cells. Canada will participate on other agreements or propose new ones in areas deemed necessary for the national interest provided there is something to gain and something to share. Canada has extensive international collaboration on greenhouse gases and climate change S&T through organizations such as the World Meteorological Organization and the United Nations Environment Programme.

Electricity Sector Profile

Appropriate indicators of federal S&T success will continue to be the same as today: carbon dioxide reduction; environmental assessment standards; waste reduction; high quality reliable power; employment; sales of products and services; testing equipment sales; standards for products and services; exports; reduction of imports; spinoffs to other fields; regional development; health and safety; training; and advancement of knowledge.

Electricity Sector Profile

Synopsis: Electricity

Importance for Wealth and Job Creation

- Electricity is vital to every aspect of modern Canadian society. Today's advanced information society, computer-aided design and manufacturing techniques and lifestyle changes all require high quality and reliable electricity supply. The energy needs of these activities cannot be met from sources other than electricity

- The electrical sector is particularly important for future wealth creation in a sustainable development context. It employs about 95,000 people directly and generates revenues of about $24.5 billion per annum. Electricity is necessary for a wide variety of applications from electric motors, electroheat, process controllers to electrolytic cells. End-use electrotechnologies can reduce waste in manufacturing, permit better process control resulting in higher quality products, release no emissions to the air at the point of use and have lower in-plant health impacts than energy from combustion.

- Electricity generation, transmission and distribution S&T permits the provision of high quality, reliable electricity supply for the domestic market and for export. Exports are projected to reach 30 TWh by 2000. Electrical equipment S&T permits the development of wide range of goods and services thus providing continuing opportunities for manufacturing, exports, employment, reduction of imports and development of SMEs across Canada. For the balance of the decade, some $3 trillion worth of electricity equipment and services will be needed in the world.

- Canada has built up considerable expertise in the generation, transmission and distribution of electricity. Canadian firms have developed and are developing, in many cases with government assistance, a wide range of speciality high quality products to serve both the national and international market. Canada can capture a fair share of the world market with continued S&T developments.

S&T Strategy

- Present Canadian capabilities are based on extensive research and development carried out over a long period and with assistance from governments. This assistance needs to be continued.

- Federal programs fund niche technology development in concert with utilities and provinces where the technology is of national interest. This is particularly important to SMEs and needs to be continued, even expanded with a major thrust in electrotechnologies. The federal government also funds, with the CEA, S&T of common interest to all utilities, thus helping smaller utilities to gain assess to a broader knowledge base.

- The federal government has developed expertise in some key areas; such as, environmental assessments, greenhouse gases and climate change, air emissions, water quality, natural habitat and electricity measurements, not fully covered by the utilities, which are necessary for policy, regulations and standards. This expertise has to be kept current to respond to broader environment and sustainability issues.

- The utilities perform most of the S&T directly related to their business in Canada. Ontario Hydro, Hydro-Québec and BC Hydro are the largest performers, with large world-class laboratories and expertise. There is no need for the federal government to develop further capabilities in these areas. There is need however to assist the utilities to transfer more of their technologies to industry especially SMEs.

- Many new technologies and innovations are needed to address future needs at home and to capture world markets. They require extensive R&D, innovative funding, new alliances and skilled manpower.