Technology Development in the Oil and Gas Industry

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and
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Industry, Trade and Technology Sector
Ministry of State for Science and Technology

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TECHNOLOGY DEVELOPMENT

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FOREWORD

In recent years, Canadian industry's competitiveness in international markets has been under considerable pressure. Overall, growth in productivity has slowed, contributing to unemployment and underemployment, inflation, and erosion of living standards. One challenge, as seen by the Ministry of State for Science and Technology, is to promote the ability of Canadian resource companies to develop and adopt new technologies as a means of increasing productivity.

Canada's rich endowment of natural resources and its considerable expertise in developing these resources provide a solid base from which Canadian companies have, or could become world leaders in specific areas of science and technology. The role that natural resources play in the Canadian economy is significant, providing employment and wealth generation in all regions of Canada and is a major contributor to our trade balance. In the present economic climate, development of new technologies has the potential to increase productivity within resource industries, thereby improving Canada's competitive position in international markets. It can also provide new business opportunities to suppliers of these technologies.

The Ministry of State for Science and Technology (MOSST) initiated the project *Technology Development in the Resource Sector* to determine how new technologies could be applied most effectively in the resource industries. An aim of this project is to examine possible actions that the federal government could take to stimulate the development and widespread application of new technologies. The resource industries being examined in the project are: agriculture, forestry, fisheries, oil and gas, and minerals. In addition, a synthesis paper of the five resource industries based on these detailed studies will provide a summary of new technologies, and actions the government can take to promote their development.

This study discusses the potential contributions of new technologies required to develop new sources of oil and gas in Canada. While the topic being addressed is large, this study has not attempted to provide a comprehensive inventory of technological requirements. Rather, the report identifies major technological areas that are expected to be important in the future and those initiatives that may be required to stimulate their development.

The report is being circulated for comment and discussion. We would be most appreciative of any feedback that you may provide.

The assistance and cooperation of numerous individuals in government, industry, universities and research centres are gratefully acknowledged. These persons are identified in Appendix A: "Contacts".

Preparation of this report has been assisted by MOSST personnel:

- Barbara Cloutier carried out literature searches and checked statistical information;

- Rick Lawford commented on earlier drafts.

The views expressed are those of the authors and do not necessarily represent those of the Ministry of State for Science and Technology.

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SUMMARY

Financial Performance

In the oil and gas industry, as in other industries, research and development expenditures are made as investments with an expected future return. Investment decisions are based on a number of factors, including the economic and policy environments, which shape the outlook for returns on investments.

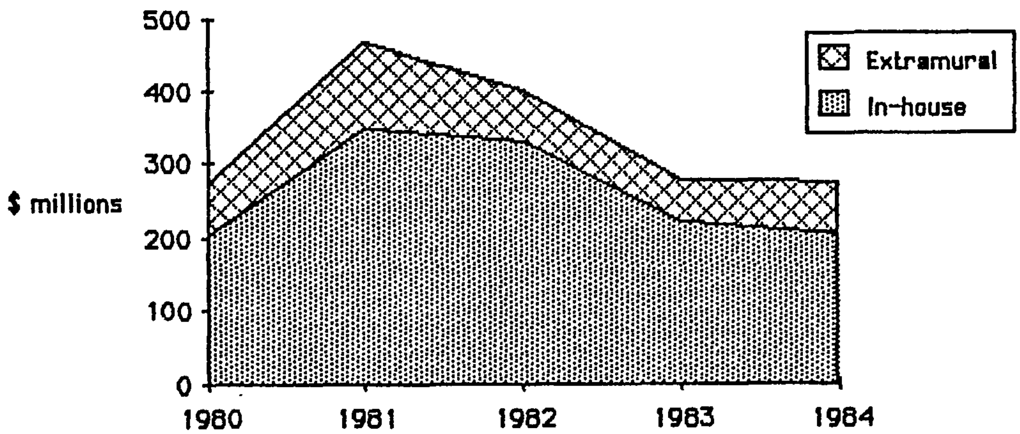
In considering the financial performance of the oil and gas industry in recent years, the following trends were evident:

- Revenues increased steadily from 1980 to mid-1985.
- Net income dropped significantly from 1980-1983 and increased in 1984.
- Since the early 1980's, there was declining profitability of the downstream sector and rising profitability in the upstream sector.
- Cash flow declined significantly from 1980-1982, increased after 1983 and declined in 1986.
- Capital expenditures increased in 1980 and then declined from these levels. Most of the declines were in the downstream sector.
- Canadian ownership and control increased substantially from 1979-1984.
- Positive energy trade balances have increased significantly with a large deficit in crude petroleum shifting to a large positive balance in 1984.

Due to a combination of factors, the investment climate during the early 1980s deteriorated significantly. Government policies, in particular the National Energy Program, discouraged foreign investment, increased taxes and reduced cash flow within the industry. High interest rates and generally poor economic conditions led to the decline of mega-projects, such as those associated with large oil sands plants. Following the dismantling of the National Energy Program and improved economic prospects, the industry began a recovery during 1984-85. In response to the rapid and steep fall in world oil prices in early 1986 ("the oil shock of 1986"), industry drastically reduced its expenditures. It is expected that investments in the development of higher cost oil and gas supplies will be curtailed significantly - a trend that has important impacts on future domestic oil supplies and also on R&D activities.

R&D Performance
R&D expenditures by the petroleum industry increased substantially between 1973 and 1981 but since then have declined significantly. While it is apparent that the deterioration of the investment climate is responsible for the drop in R&D activities, the level of R&D activities was not responsive to the recovery of the industry. By 1983, industry expenditures on R&D had declined to about 0.6% of sales in comparison with previous years where expenditures were 1.2% of sales. Yet, it has recently been demonstrated that during the period 1977-81, within the oil and gas and mining industries, the return on investment from R&D exceeded that of capital expenditures (31% vs. 21%). A large and rapid drop in R&D in the upstream sector has occurred since 1981: expenditures in exploration and production R&D have declined by 50%, and have been reduced by 60% for *in situ* R&D. This trend is of particular concern as it is the upstream sector of the industry which will bring new supplies of oil and gas onstream in the future.

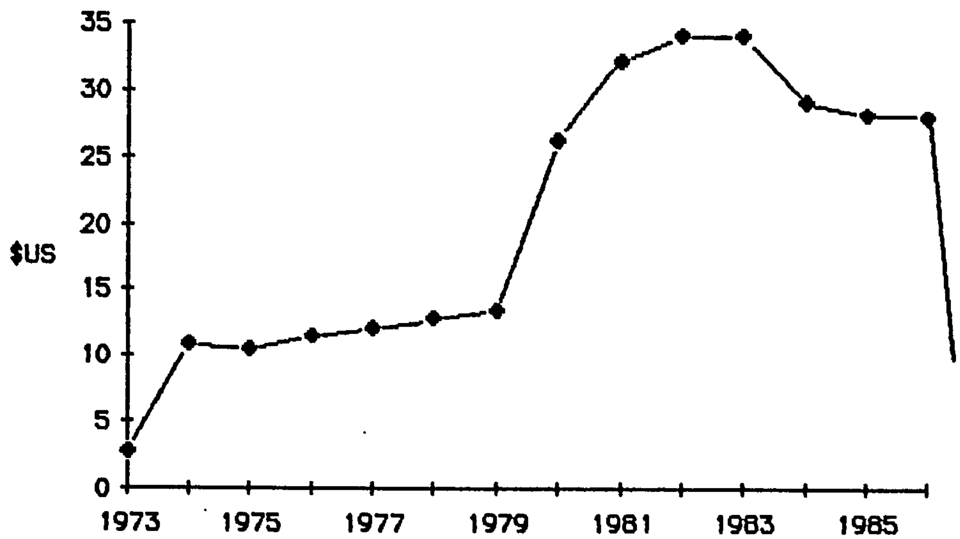
R&D Expenditures,
Canadian Oil and Gas Industry



Outlook
While Canada has abundant supplies of oil and gas in the frontiers, heavy oils and oil sands, their profitability is very sensitive to oil prices. As a result, the currently low prices will result in the delay of a number of projects. With lower oil prices, consumption would tend to increase, while exploration activities would decline. Both trends would be detrimental to domestic energy security goals. Conversely, some have suggested that Canada should take advantage of present low prices by increasing imports and preserving existing domestic reserves of oil. Still others suggest that the goal of energy self-sufficiency be abandoned as a planning tool. Rather, it has been suggested that resource policy would focus on net economic benefits of income and employment.

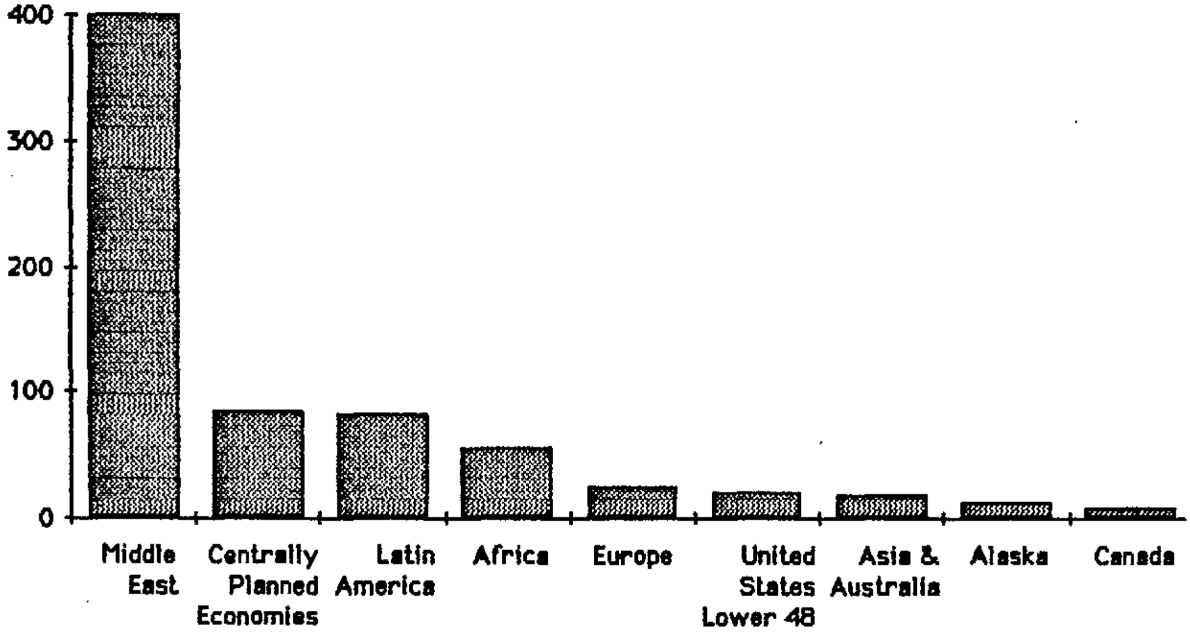
At present, opinion is divided as to whether the world price of oil at less than US$15 per barrel is a temporary or an enduring phenomenon. Historically, oil prices have been volatile. By controlling surplus supply and having large amounts of inexpensive oil, the Organization of Petroleum Exporting Countries (OPEC) has been the key agent in price-setting. The OPEC share of the world oil market has, however, declined from 53% in 1973 to 32% by 1984. Canada and other nations of the Organization for Economic Co-operation and Development (OECD) have, over the past decade, initiated a number of measures to reduce their dependence on OPEC producers. Cohesion among OPEC members has eroded considerably, resulting in members selling oil at discounts and exceeding production quotas. As OPEC nations have large amounts of inexpensive oil, lower world prices are expected to increase OPEC's market share and thus its control of the world oil market.

World Oil Prices
($US/barrel)

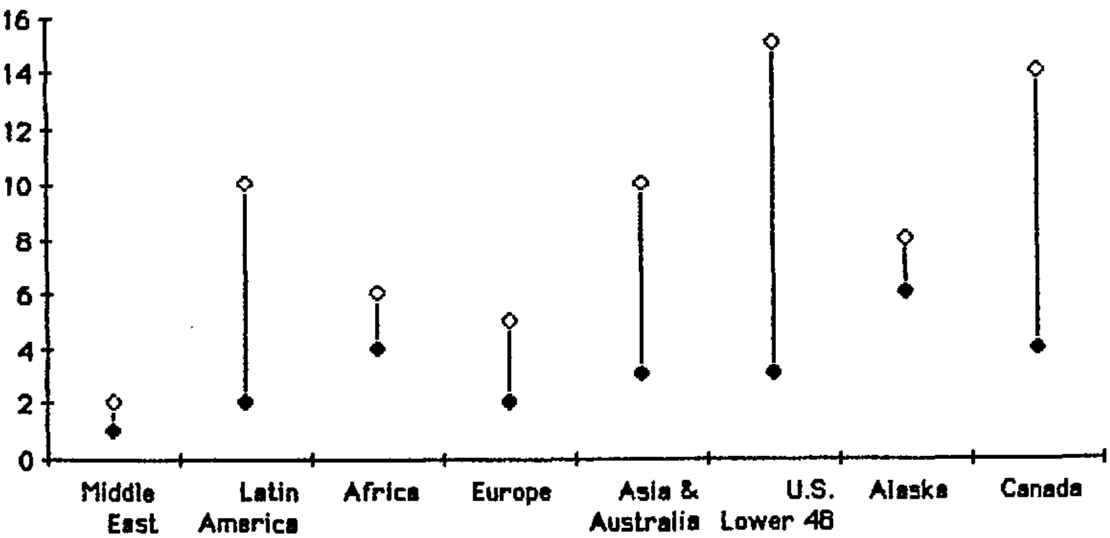


A number of related factors have an influence on world oil prices: conservation, substitution, slow economic growth, new discoveries resulting in significant increases of proven oil reserves, and an increased proportion of oil sales on the spot market rather than through long-term contracts. World-wide, abundant oil resources are available to the year 2000. Some 42% could be produced at less that US$12/bbl., and 75% could be produced at less than US$20/bbl. (compatible with market prices of about US$30/bbl.). These resources are, however, highly concentrated in the Middle East and in planned-economy countries: about 60% of ultimate oil resources exploitable at less than US$20/bbl. are available from these regions. The downward pressures on world oil prices are expected by some analysts to persist through the 1980s. A result would be a major and sustained contraction of the Canadian oil and gas industry.

World Oil Reserves
(billions of barrels)



World Oil Production Costs
($US/barrel)

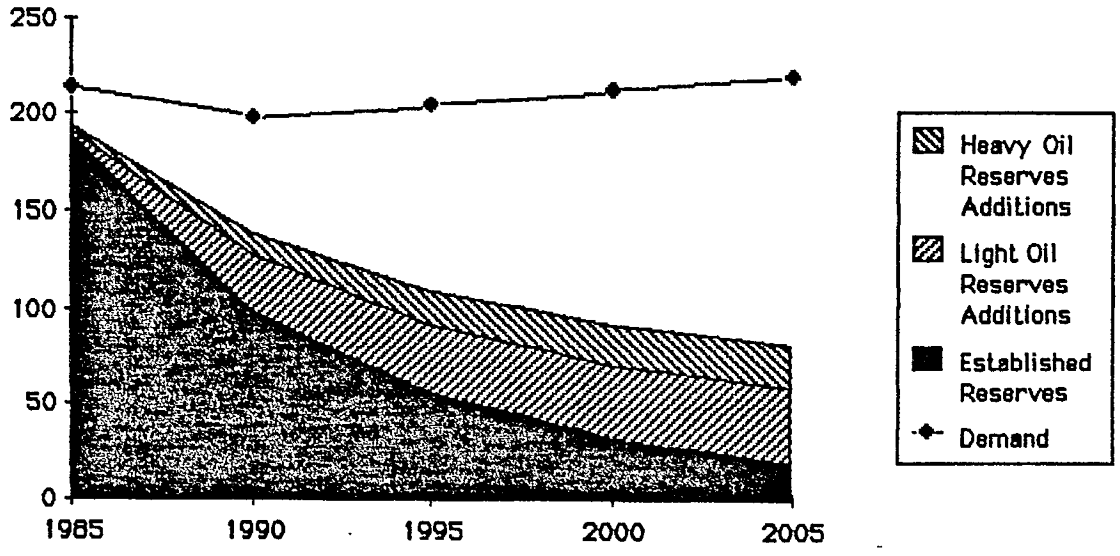


Each scenario - of high or low world prices - will have important and direct implications for domestic energy supplies, R&D activities and technology development. In the case of lower prices, emphasis would be given to reducing production costs associated with exploration and production from conventional producing areas in Alberta and Saskatchewan. Under a scenario of higher prices, other sources of oil supplies would be developed, requiring a variety of new technologies. Energy policies, and related R&D policies, will be required to respond to various price scenarios.

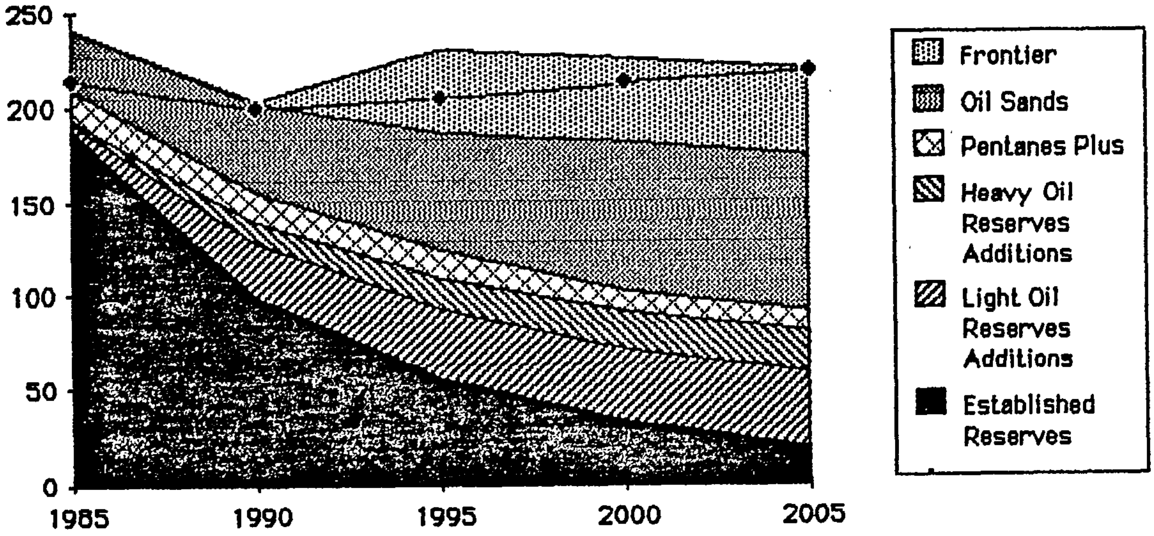
Canada presently relies heavily on conventional oil from the Western Canada Sedimentary Basin to meet its oil requirements. The rate of new discoveries has been declining from this region, which is now in a mature stage of development. Costs of finding new oil reserves in Western Canada have risen significantly in recent years and this trend is expected to continue in the future. Compared to conventional supply areas in Canada, offshore oil, oil sands and heavy oils are becoming an increasingly attractive investment.

If imports are to be minimized, development of oil from oil sands, enhanced oil recovery and the frontier regions is essential to meet Canada's demand for crude oil. At present, there is no production from the offshore frontier regions, yet this source is expected to contribute 28% of total domestic light oil production or 20% of all crude production by the year 2005. Oil sands, while now providing less than 15% of domestic oil production, are expected to meet 38% of Canada's oil production in 2005. Together, oil sands and frontier oil have been projected to account for about 60% of Canada's productive capacity in crude oil within twenty years. Enhanced oil recovery would provide about one-half of reserves additions in conventional areas during this period.

Forecast of Productive Capacity of Conventional Oil and Heavy Oil Additions from Conventional Areas
(thousands of cubic metres/day)



Forecast of Productive Capacity of Conventional Oil
(thousands of cubic metres/day)



With lower oil prices, these forecasts are now in question as investments in projects to increase Canadian oil supplies are expected to be curtailed. Given the long lead times from project concept to actual production, these new sources cannot be expected to be developed in a timely manner if investment decisions are based on uncertainties in volatile world prices.

Opportunities
Under a scenario of higher oil prices, significant opportunities exist in the development of new technologies. Over the next ten years the oil and gas industry could invest approximately $50 billion in Canada for new major projects that would provide a strong impetus for R&D and technology.

Opportunities also exist in the international development, sale and transfer of technologies. Canadian firms can both adopt foreign technologies and supply other countries with oil and gas related technologies. With a small domestic market, international market access is necessary and desirable both in obtaining technologies at low costs and in providing a larger market for Canadian-developed technologies. Technology transfer licensing agreements with other countries have proven to be effective in upgrading Canadian expertise. Canadian industry has developed technological capabilities that have world-wide acceptance and commercial viability.

Strengths
Canada has many strengths in oil and gas development, including:

- large oil ånd gas reserves and potential
- a strong and viable oil and gas industry
- well-educated and trained professionals
- expertise in operating in cold, remote offshore regions
- expertise in extracting heavy oils and oil from the oil sands.

As production from mature conventional areas declines, these strengths will become increasingly important. It is apparent, however, that decreased investments and the significant recent declines in R&D expenditures will erode these strengths.

Production of oil and gas from the frontiers, oil sands and through enhanced oil recovery all require sophisticated and in many cases, new technologies. As such, R&D will be essential to ensuring domestic oil security, and can enhance the value of Canada's energy trade balance through cost-effective development of oil, natural gas and refined products.

Government Policies and Programs
The federal and provincial governments have established a wide variety of policies, agreements and programs that have both direct and indirect effects on oil and gas-related technology development. Policies, regulations and fiscal regimes provide the environment in which the industry operates. In large measure that environment détermines the pace and location of industry's activities. While it is not the purpose of this report to prescribe energy policies, an understanding of various policy directions and future options is necessary insofar as energy policies are a primary driving force determining R&D activities.

The dismantling of the National Energy Program provided a positive stimulus for investment until lower world oil prices arrived. Energy policies in the future will have to address the issues of:

- assistance to an industry under pressure from lower prices, through measures such as tax and royalty reductions, exploration incentives, floor prices or import taxes, balanced with

- the benefits of lower oil and gas prices to consumers and industries such as manufacturing and transportation;

- shrinking government revenues;

- maintaining continuity in expertise and leadership in oil and gas R&D;

- energy security: decreasing exploration activities in higher cost regions of Canada and increasing consumption due to lower prices could increase reliance on imports. Development of higher cost sources require long lead times to bring supplies to market. Conversely, increasing imports could reduce demands on domestic supplies, thus improving energy security.

About 300 government policies and programs among 17 federal departments directly or indirectly affect offshore oil and gas activities. These consist of policies, incentives and taxes, regulations and licensing requirements, common user services, data and information sources and advisory services. Government policies and programs are also utilized as a means of promoting technology development. Various policies in place encourage R&D in oil and gas research, and emphasize the maximization of local and domestic benefits. A wide range of funding programs are available for oil and gas R&D.

Increased cash flows and the potential for higher profitability levels under new energy policies were expected to lead to increased R&D activities. Uncertainties with lower oil prices could have a dramatic effect on investments made in the development of the more expensive oil and gas sources in offshore areas, oil sands and heavy oil recovery.

Technological Support

R&D is performed by oil and gas companies, consulting and supplier firms, governments, universities and various research centres. R&D sponsored by the petroleum industry is performed for the following closely related reasons:

- to enable operations to take place under difficult operating conditions, e.g. offshore and underground
- to reduce operating and capital costs
- to improve the safety and reliability of operations
- to meet government regulatory requirements.

The work of the numerous organizations in industry, government and universities over the past 15 years has resulted in Canada being at the leading edge in technologies required for operating in cold, remote areas typical of Canada's frontiers. This complex array of companies and agencies conducting offshore R&D has led to a variety of coordinating mechanisms to reduce duplication of effort and secure the benefits of technology transfer. As a result, technologies tend to diffuse rapidly.

Canada has also developed a leading international capability in oil sands and heavy oils R&D. Canadian technology, equipment and expertise are marketed around the world, with formal agreements for technology exchange and research existing with eighteen countries.

Technological Requirements

A. Offshore Oil and Gas

The exploration, production, and transportation of offshore oil and gas require technologies that enable operations to be conducted in various environmental conditions. Depending on the location, these operating conditions include:

- the presence of ice
- high sea states
- varying water depths
- unstable seafloor conditions
- the presence of permafrost
- cold climates
- darkness.

To ensure safe operations and minimal down-time, equipment and systems must be rugged and fail-safe. Development of offshore resources provides a significant opportunity for the development of medium to high technology ocean industries.

Technologies required are in the major areas of:

Information Acquisition and Management
- Acquisition, transmission, reception, analysis and integration of data on operating conditions
- Models for design and decision-making

Ice-Classed Vessels Optimization

Drilling and Production Structures
- Permanent year-round structures
- Optimization for a wider range of loads
- Optimization in design and materials
- New methods for operations in deeper waters

Ice Engineering and Ice Management Techniques
- Reducing down-time and improving safety
- Ice-structure interactions
- Ice-breaking systems, iceberg towing
- Ice scour avoidance techniques

Materials
- Development of materials, e.g. concretes, steels, ice, sealants, having variety of desired properties

Subsea Systems
- The ability to complete wells, produce and transport hydrocarbons from the wellhead safely to surface facilities, vessels or to shore

- Advances in seafloor hardware and systems
- The ability to monitor, maintain and control subsea equipment
- Geotechnical R&D developments
- Submarine transport

Environmental Protection Technologies
- Pipelines through frozen ground
- Oil spill countermeasures
- Environmental monitoring and mitigation

Natural Gas Management
- Cost-effective processing of presently uneconomic natural gas

Safety Equipment and Systems
- Safety design
- Evacuation
- Search and rescue

B. Oil Sands and Heavy Oils

The principal technological requirements for the development of oil sands lie in the development of *in situ* techniques for bitumen recovery from deeper deposits. Development of heavy oils will require further improvements to enhanced oil recovery (EOR) techniques. Upgrading will open new markets for bitumen and heavy oils while alleviating projected shortages of diluents. Major areas for new technologies include:

Oil Sands Mining
- Improvements in overburden removal
- Advances in bitumen extraction from mined oil sands
- Simplification of equipment used in handling abrasive slurries
- Basic research in fundamental chemistry and physics of extraction

In-Situ Recovery of Bitumen and EOR
- Improvements to various EOR techniques, especially combustion
- Flow control techniques
- Emulsion treatment
- Underground access and horizontal drilling techniques
- Bottomhole instrumentation
- Improved lifting systems and sand control
- Water treatment
- Increased efficiency of steam generation

Upgrading
- Reducing sulphur dioxide emissions from coke burning
- Co-processing of heavy oil, bitumen and coal
- Contaminant and catalyst treatment
- Use of oil sands bitumen as a feedstock for petrochemical production

Information Technologies
- Deposit modelling
- Air quality prediction systems
- Control systems and instrumentation

C. Pipelines

Pipeline Design
- Higher operating pressures
- Steels for special applications
- Corrosion & coatings

Construction
- Welding techniques
- Transportation of pipe to the site

Compressors and Pump Stations
- Increased fuel efficiency
- Optimization

Inspection
- Increased sensitivity of equipment
- Magnetic methods
- Measurement of stress

Metering, Control and System Optimization
- Improved meters
- Expert systems and improved data acquisition
- Two-phase flow
- Remote operations

Permafrost
- Basic research
- Forces on pipes

Offshore Pipelines
- Ice scour avoidance/protection

Slurry Pipelines
- Coal/water mixtures
- Metallurgical coal slurries
- Coal/water/chemical gel slurries
- Coal agglomeration

Barriers to Technology Development

The following barriers to the development of new technologies have been identified in this study:

- Sensitivity of projects to oil prices. Canada is a relatively high cost producer of oil and gas. As world prices have recently dropped dramatically, planning the development of new sources of hydrocarbons has become extremely difficult. Existing and new investments are being curtailed.
- Significant declines in industry's R&D expenditures since 1981.
- The perception by industry that the approvals process for frontier projects is onerous.
- The conservative, risk-averse nature of the oil and gas industry.
- Limitations in financing of R&D and technology development.
- Difficulties in staffing and maintaining teams of experts.
- Inherent limitations in the management of R&D.
- Limitations of government funding programs.
- Lack of credibility and track record of innovative firms.
- Insufficient use of consultation, communication and feedback mechanisms.
- Confidentiality of data.
- Lack of common standards in data.
- Limited markets, uncertainties in the development of technology, and international competitition in fabrication and manufacturing.
- A relatively weak supplier community (although niches in world markets have been found and successfully exploited).

Positive Influences in Technological Development

- The oil and gas industry began a recovery from a serious decline in net income during the early 1980s that could continue if higher oil prices were in place.
- The industry reinvests a substantial portion of its cash flow into operations and capital expenditures.

- While Canada has abundant supplies of oil and gas, a substantial increase in production from the offshore, oil sands and heavy oil reservoirs will be required to meet future demands. Although costly, compared to conventional domestic supplies the sources are becoming increasingly attractive and will require new technologies.

- Energy policies promote the development of these sources. Canada has a strong commitment to energy security.

- Various other policies encourage R&D and several generous funding programs are available.

- A large international market exists for oceans services and hardware.

- Certain federal R&D programs have explicit commercialisation plans for the development of new technologies.

- The federal government has taken a "portfolio" approach to energy R&D.

Summary Assessment

A significant number of sophisticated technologies may be required for the exploration, production and transportation of future oil and gas supplies in Canada. The pace of developing new sources of oil and gas, largely determined by world oil prices and Canadian energy policies, will have a direct bearing on which technologies will be required.

Technology development associated with oil sands and heavy oils is adequately funded and is well-managed. It is concluded that no major new initiatives by the federal government are required to stimulate the development of technologies in this area.

In view of the adequacy of existing work and the limited outlook for construction of major new lines, no major improvements are required in support of pipeline R&D. There is room for improvment, however, in better coordination of existing efforts.

Canada has a strong capability in research, science and technology required for offshore development in cold regions. Further efforts could maximize the effectiveness, relevance and value of R&D and increase technology development by industry, government, universities, research centres and supplier companies.

The oil and gas industry faces serious challenges in the coming months and years. The Standing Senate Committee on Energy and Natural Resources reflected these concerns in August 1985:

> *"Complacency is invading energy policy-making. With the current glut of crude oil in world markets, we see little concern about future security of supply. But petroleum is not simply another economic commodity whose availability will be adequately regulated by the workings of the marketplace. We reject the premise that energy, in its various manifestations, is nothing more than an article of commerce; at times environmental, social, strategic or political considerations hold sway over market forces....Oil is no less a strategic commodity today than it was in the 1970s. Terrorism or war in the Middle East could disrupt the global flow of oil at any time - the 1973 Arab oil embargo and the Iranian Revolution showed that even the prospect of shortage can cause panic.... The oil problem has not disappeared; it is merely dormant. This period of relative calm should be used to plan carefully for a more secure energy future, one which minimizes the importance of oil and our reliance on imports."*

While the "period of relative calm" has since disappeared, the emphasis on continued planning for a secure energy future supported through technological development should remain a priority of Government.

Rationale for Supporting New Technologies
The reasons for increasing and improving the level of R&D and technology development related to oil and gas are to:

- ensure the security of domestic oil and gas supplies,
- increase the productivity and competitiveness of the industry,
- encourage industrial innovation,
- provide business opportunities for suppliers,
- generate scientific expertise,
- enhance the ability of Canadian firms to adopt foreign technologies,
- foster international cooperative projects,
- provide employment,
- protect the environment.

Policy Objectives
Policy objectives have been identified which will have to be addresed if Canada is to maximize the effectiveness, relevance and value of oil and

gas R&D performed by industry, government, universities, research centres and suppliers. These objectives are:

1. To ensure that opportunities are fully exploited, constraints or barriers to technology development are overcome, and technology development is accelerated.

2. To increase private investment in innovation.

3. To maintain leadership in oil and gas technologies and expertise.

4. To enhance the role of government R&D programs in technology development and to improve the relevance and usefulness of government R&D programs.

5. To increase the role of universities in oil and gas R&D.

6. To provide more opportunities for the performance of R&D.

7. To improve the diffusion of technology.

Policy Options
In view of these objectives, a number of policy options are presented for consideration by MOSST, other departments, industry and other R&D performers. A more detailed discussion of these measures is contained within Chapter 6.

1. Strategic Planning of Innovation

- Increased emphasis should be given to the flow of technology through the innovation process.

- More effective use of explicit innovation process criteria should be used for evaluation and planning of R&D programs. These criteria include market assessments, technical feasibility, risk/reward assessments, impacts on industry, and priority technologies.

- While the limitations to planning are recognized, without continuity of efforts, a hiatus in oil and gas technology development could occur. Canada could then be faced at some point in time with a need to undertake "crash" programs.

- To maintain leadership in oil and gas related technologies and to develop nascent Canadian capabilities will require increased funding for innovation. Such expenditures should be made as investments having a return rather than expenses that are lost.

- Industry should be encouraged to increase expenditures on R&D from present levels (which are less than 1% of sales).

- Joint planning of long-term R&D programs with associated funding commitments should be initiated for areas of national priority.

- The establishment of a Canadian Oil and Gas Technology Institute should be considered to provide a national approach to identifying priorities and strategies for oil and gas R&D.

2. Emphasizing Cooperative R&D: An "Open Architecture Approach"

- The most effective means of promoting technology development and diffusion is through cooperative R&D. The focus for expanded efforts in this area should not be on reorganization of existing institutions, but in improving their linkages.

- An "open architecture" approach is proposed to overcome the relative isolation and improve the effectiveness and focus for technology development.

- Specific methods to achieve this are: increased access of R&D programs to other R&D performers and funders; promotion of centres of excellence; increased personnel exchanges; and encouragement of industry to have outside advisors on their research committees.

3. Improving Government R&D Programs

- Government should carefully consider the present and possible roles of non-government advisors and directors for each federal R&D program.

- While increased funding is difficult to secure in the present cost-reduction environment, government should identify and proceed with those R&D projects that are investments with significant positive returns. Government funding of oil and gas R&D appears to be barely adequate to meet the objectives of maintaining leadership and developing Canadian capabilities, particularly considering the magnitude of oil and gas projects and potential government revenues.

- Government departments should investigate the possibility of allocating discretionary funds for application to urgent or timely opportunities as they arise.

4. Improvements to Industry Support Programs

- The Government should prepare a federal response to the Wright Task Force report.

- New pro-active approaches in supplier development should be explored.

- Regional delivery systems, single-window delivery approaches and "buddy" systems for program delivery should be encouraged and strengthened.

- The mandate of program managers should explicitly encourage a market-oriented and entrepreneurial approach in delivery of programs.

- Government and NSERC should ensure that industry and universities are fully aware of the criteria applied by NSERC in matching funding arrangements.

- Government departments should improve their ability to respond to urgent or timely opportunities as they arise.

- Government should investigate other ways to increase industry funding of universities.

5. Addressing Information Access, Dissemination and Confidentiality Policies

- Government's "networking" and communications programs to improve awareness of R&D activities should be expanded.

- A clear and consistent policy concerning confidentiality of government-funded R&D should be developed.

6. Utilization of Regulatory Approvals Process

- R&D requirements in support of project applications should be identified.

- Greater emphasis on R&D should be given within the approvals process.

- A "code of good conduct" developed by industry should include reference to R&D performance.

- Closer ties should be encouraged between the oil and gas industry, government and technology-intensive companies.

- CMOP and DRIE should play an important role in identifying market opportunities for technology-intensive products and services, and should identify these areas explicitly.

- Increased emphasis should be given in regulations on performance rather than design requirements and adoption of "best available technology" policies should be considered.

7. Enhancement of Export Policy Measures

- Efforts should be aimed at trade liberalization, bilateral and multilateral technology agreements.

- A niche strategy in selected technologies should be adopted.

- Joint ventures for acquisition of foreign technologies should be promoted and where appropriate, Canadian technology should be encouraged to supplant foreign technologies.

- Canadian trading companies and consortia should be promoted.

8. Strengthening Contracting-Out and Commercialisation Policies

- Contracting-out and commercialisation policies deserve continued support and strengthening.

- Government should ensure that adequate resources and leeway within the bureacuracy are provided for project managers to continue and improve the delivery of programs consistent with the contracting-out and commercialisation policies.

9. Development of Northern and Oceans S&T Strategies

- Longer-term strategies and supporting policies to stimulate and coordinate national research programs in these areas should be developed.

1. OVERVIEW OF THE OIL AND GAS INDUSTRY

Introduction
The oil and gas industry is an important component of the Canadian economy, providing the largest portion of energy supplies (68% of demand) and the greatest value of energy production, while contributing significantly to Canada's trade balance. Some of the key features of the oil and gas industry in 1984 were:

- Value of Production..........................	$ 24.2 billion
- Revenues...	$ 64.5 billion
- Net Income......................................	$ 3.7 billion
- R&D Expenditures............................	$ 273 million
- Canadian Ownership...........................	40%
- Direct Employment............................	257,000
- Capital Expenditures..........................	$10.1 billion
- Trade Balance of oil and natural gas...	$4.9 billion

The major sources of hydrocarbons and areas of oil and gas activity are:

- conventional sources of oil and natural gas, primarily from the Western Canada Sedimentary Basin,

- heavy oil, situated in areas such as the Lloydminster area of Alberta and Saskatchewan,

- synthetic light oil from oil sands located in Alberta,

- frontier oil and gas - located on the Canada Lands, principally the Beaufort Sea, the Arctic Archipelago and the East Coast.

Phases of Activity
The oil and gas industry has five major phases of activity: exploration, development and production, transportation, oil refining and gas processing, and marketing. The "upstream" segment refers to exploration, development and production; the "downstream" segment consists of the refining, marketing and transportation phases.

The first steps in the exploration phase consist of geological and geophysical surveys. In promising areas exploratory or wildcat wells are drilled, and in the case of successful wells, additional appraisal or delineation wells are drilled to determine the size and extent of the reservoir. If encouraging results are obtained, the company may proceed with extraction of hydrocarbons during the production phase.

Once produced, crude oil and gas undergo primary processing in the field to remove undesired components and are delivered to trunk pipelines. As over 95% of oil and gas production is within Alberta and Saskatchewan and the largest markets for oil and gas are in Ontario, Quebec, British Columbia and the United States, transportation is a significant component of the oil industry. Oil, oil products and natural gas are transported primarily through a large network of pipelines located within Canada and extending into the United States.

A large portion of domestic oil production is delivered to some 30 refineries throughout Canada. Principal products of refineries are gasoline, aviation turbo fuel, kerosene, and diesel, light, and heavy fuel oils. Refiners market oil products to commercial and industrial accounts, oil company distributors, and independent resellers. After processing through gas plants, natural gas is distributed to industrial, commercial and residential users. Natural gas and oil products are also delivered to some 70 petrochemical plants where hundreds of different products are produced.

The technological requirements for each these five distinct phases vary considerably. In frontier energy development, however, there are common technologies associated with marine operations among the exploration, production and transportation phases. Heavy oils and oil sands have common R&D requirements in the production, transportation and refining of viscous oils.

R&D and Financial Performance

In the oil and gas industry, as in other industries, research and development expenditures are made as investments with an expected future return. Investment decisions are based on a variety of factors, including the economic and policy environments which shape the outlook for returns on investments. The Conference Board of Canada has found that, within Canadian organizations, R&D spending within individual firms is determined primarily in the following ways:

- on a project-by-project basis,
- as part of the strategic planning process,
- from the productive results of the R&D program, and
- as a percentage of sales.

As well, R&D is viewed as a means to enter new markets and to maintain existing market shares in domestic and export markets.

Factors adversely affecting R&D programs in all industries include: shortage of financing, weak market demand for products, lack of R&D personnel, and certain government policies. In recent years, the primary sector in Canada has undergone rapid changes in response to the recession, high interest rates, and declining world commodity prices. This has resulted in declines in investment outlays, including investments in R&D, which declined by 17% in the primary sector during 1983.

The relation of R&D and industrial performance has been described by the Science Council of Canada:

> *"Policies structured on the assumption that R&D alone creates industrial strength are found to be insufficient. In fact, the reverse is true; industrial strength creates the fertile ground necessary to promote excellence in research and development. For this reason, any policy seeking to increase Canada's capacity to develop technology will have to concentrate on creating a healthy business climate."*

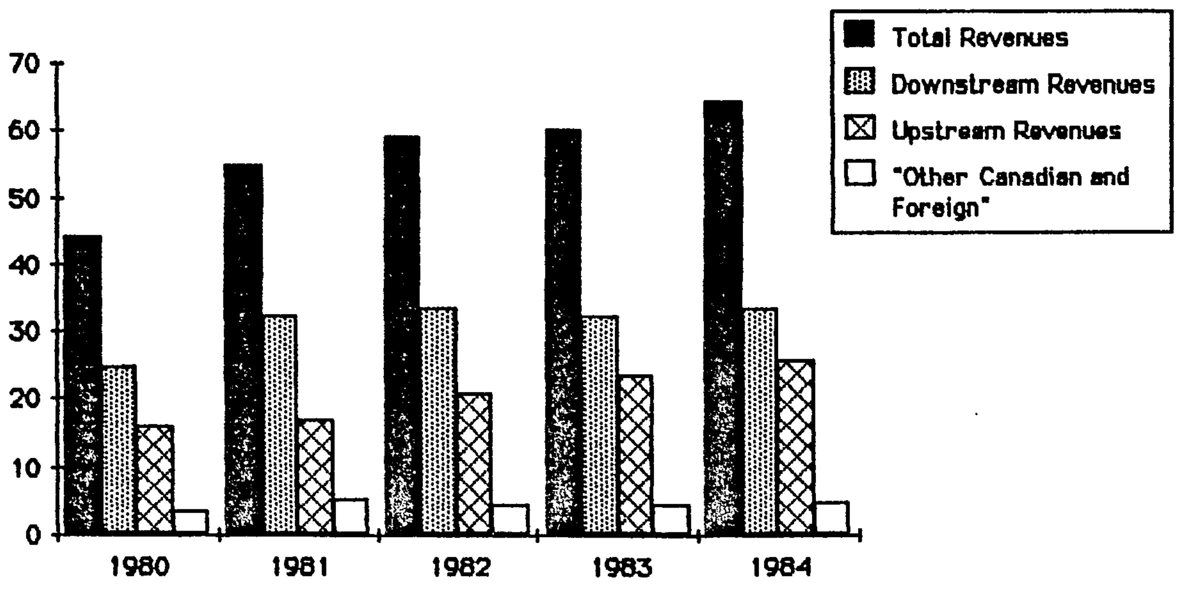
Within the following sections, the characteristics and financial performance of the oil and gas industry are reviewed and related to R&D activities.

FINANCIAL PERFORMANCE AND OPERATIONS

Financial Performance

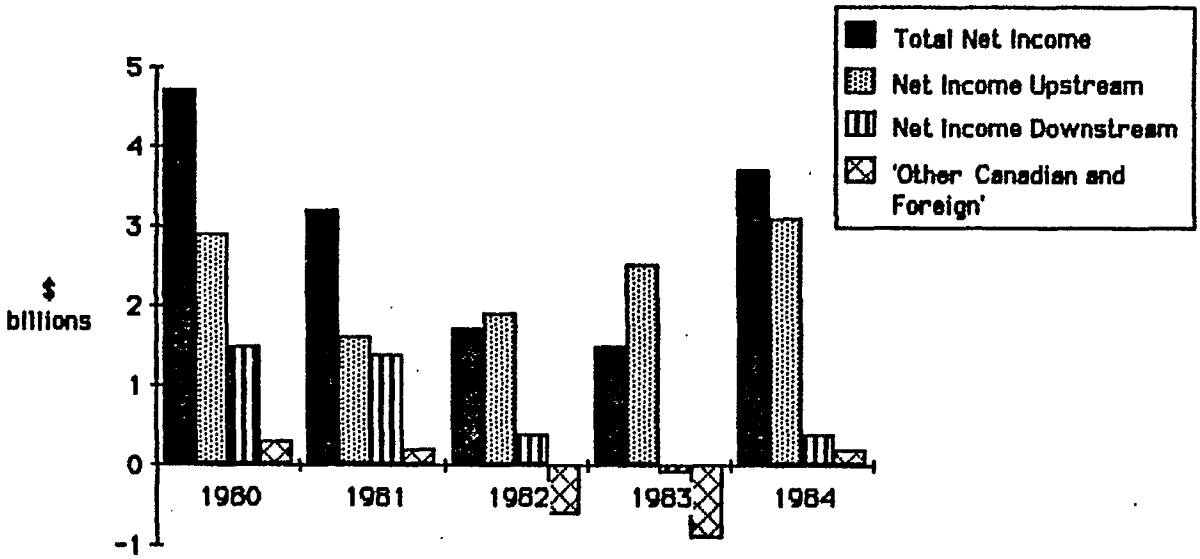
During the period 1980 to 1984, revenues increased at an average annual rate of 10%, some 3% greater than inflation. Production of crude oil and natural gas increased significantly during this period. Higher wellhead prices improved growth in the upstream component. Revenues of the oil and gas industry in 1984 amounted to $64.5 billion, with net income from operations amounting to $3.7 billion. Revenues continued to rise in the first half of 1985. If prices remain at April 1986 levels, upstream revenues in 1986 will decline by about $10 billion from 1985 levels.

Figure 1.1
Revenues, Canadian Petroleum Industry
($billions)



During the period 1980 to 1984, net income dropped substantially in 1983 but increased in 1984. New energy taxes and reduced downstream profits were the major factors in the decline. Of the oil and gas industry's total net income in 1984, over $3 billion came from upstream operations, $372 million from downstream operations, and $235 million came from foreign activities. The most profitable area of the industry has been in upstream activities. In 1985 the industry's net income accounted for 24% of the total net income of all non-financial companies in Canada.

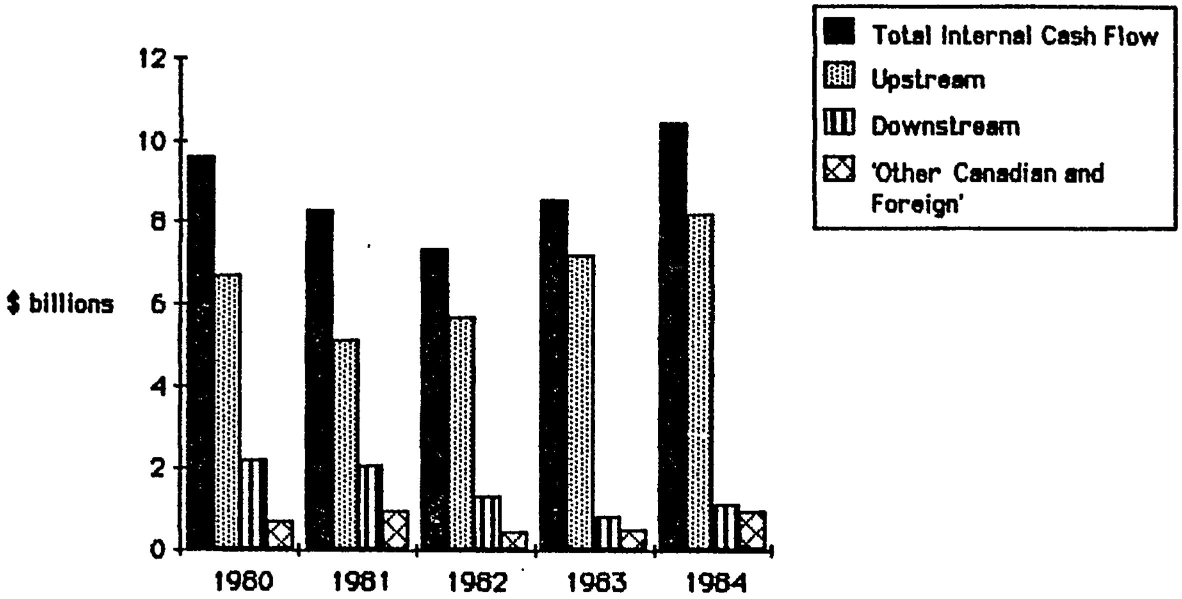
Figure 1.2
Net Income, Canadian Petroleum Industry



Rate of return on capital employed was 5.2% for the industry by mid-1985. The rate of return on shareholders' equity for the industry was 10.7%, compared with 10.3% for all other non-financial industries. Dividend payments increased steadily during the period 1980 to 1984 at an average annual rate of 8% per year.

Internal cash flow declined until 1982 and increased in following years, but as a percentage of revenue it has declined sharply from 22% in 1980 to 16% in 1984.

Figure 1.3
Internal Cash Flow, Canadian Petroleum Industry



During 1984, of the total of $23.1 billion in revenues available for sharing, industry received $12.4 billion (53.6%); the provincial governments, $7.3 billion (31.5%); and the federal government received $3.4 billion (14.9%). Provincial and federal shares came from a variety of taxes, royalties, charges and land payments. For each dollar drop in world prices, industry and government revenues from oil and gas decline by about $600 million. If present oil prices continue, total upstream revenues will decline by about $10 billion in 1986 compared to 1985. Of this amount, federal and provincial governments will receive about $6 billion less in revenues, and industry will receive $4 billion less in revenues.

The oil and gas industry reinvests a substantial portion of its cash flow into operations, a potentially positive stimulus to R&D. Capital employed by the industry in Canada amounted to $60 billion by year-end 1984. In 1984, capital expenditures by the petroleum industry as a proportion of total capital expenditures by all non-financial industries was 36%. About 80%, or $10.2 billion, of industry's cash flow was allocated to capital expenditures. Of this, $7.7 billion was directed to upstream operations. Downstream activities and other activities accounted for $1.8 billion and expenditures abroad accounted for $.7 billion. Cash flow of the total industry has been reduced by 50% during early 1986.

Figure 1.4
Capital Expenditures by Application,
Canadian Petroleum Industry 1984

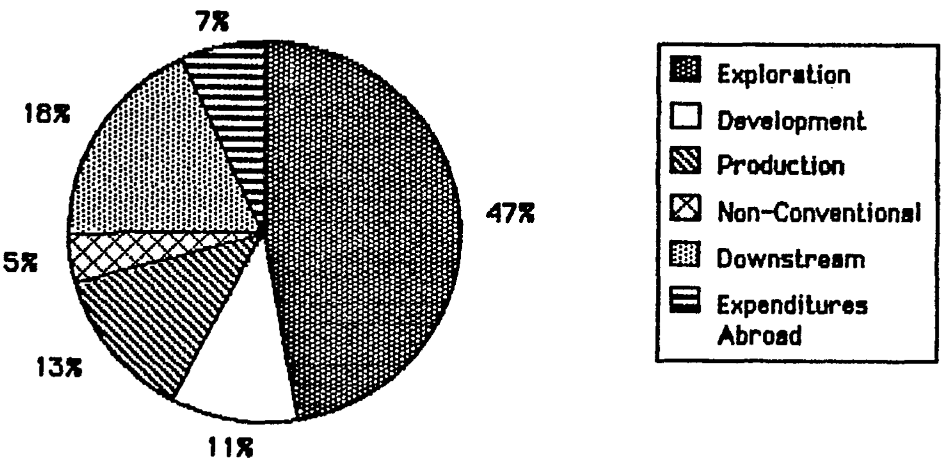
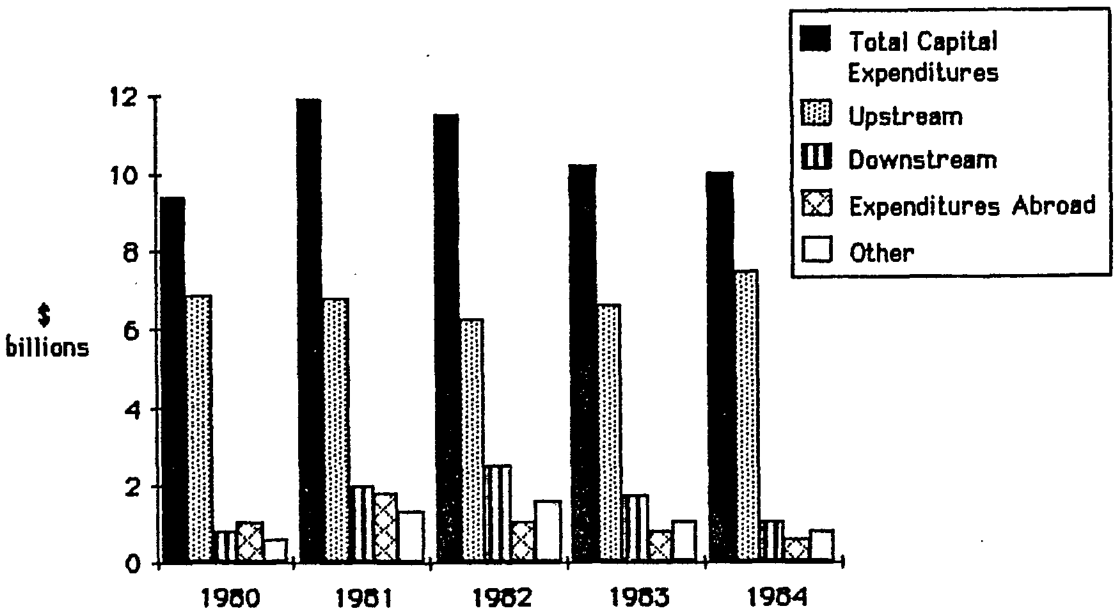


Figure 1.5
Capital Expenditures 1980-84,
Canadian Petroleum Industry



Capital expenditures have declined since 1982 as downstream projects were completed, investment abroad was reduced and fewer new projects were started. Large decreases in capital expenditures are accompanying the recent fall in oil prices. For example, capital budgets of members of the Independent Petroleum Association of Canada were cut by 50% during the first quarter of 1986. Fifty percent of these cuts were in exploration, 40% in development, and 10% in production.

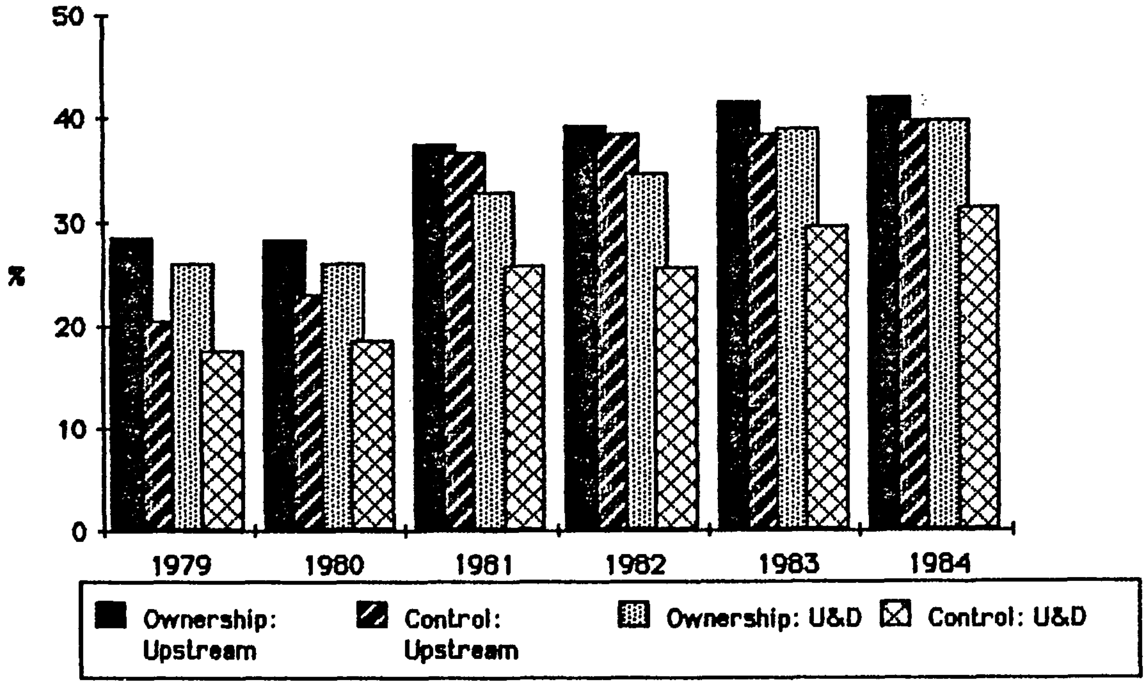
Reinvestment ratios to internal cash flow reached over 138% in 1982. This is attributed to the large expenditures made in downstream operations. By 1984 the total reinvestment ratio amounted to 80% of cash flow.

Canadian and Foreign Ownership

The traditionally high level of foreign ownership of the Canadian petroleum industry has declined in recent years as a result of government policies and the increasing maturity, size and strength of domestic companies. Multi-national oil and gas firms have brought advanced technologies from around the world to Canada. On the other hand, concern has been expressed that Canadians do not have sufficient opportunity to participate in the industry and benefit from its spin-off effects. Also of concern is the large amount of the net outflow of funds from Canada, amounting to $1.2 billion a year in 1984. Foreign ownership has been seen by some to limit the amount of R&D being performed within Canada, as foreign-controlled subsidiaries have access to technology from their parent companies. The matter of foreign ownership and its relation to R&D is addressed later in this chapter.

Canadian ownership of the oil and gas industry was approximately 42% in 1984 (based on upstream revenues). Canadian control of upstream revenues amounts to approximately 40%, of which nearly one-third was within the public sector. Canadian control over upstream and downstream revenues was 31.4% by year-end 1984. As recently as 1977, Canadian control of all petroleum-related revenues was about 12%. Figures from 1983 indicate that the Canadian ownership of companies based on upstream and downstream revenues was: 22% of integrated companies, 63% of senior companies, and 58% of junior companies.

Figure 1.6
Canadian Ownership and Control
of Petroleum Industry



The trend over the period 1979 to 1984 has clearly been towards increased Canadian ownership and control of the industry, one of the principal aims of the National Energy Program.

Size and Ownership

In terms of size and ownership the industry is most often described as consisting of: foreign majors, foreign juniors, Canadian majors, medium-sized Canadian firms, and Canadian juniors. The terms "senior" and "major" are frequently used interchangeably. The "senior" companies have been defined as receiving more than 1% of total industry revenues. Industry's revenues during 1984 amounted to $64 billion; thus, a "senior" had sales of $0.6 billion or greater.

Foreign majors, revenues, assets and Canadian Ownership Rating (COR) as of year-end 1984 are shown in Table 1.1. Assets and revenues of Canadian major oil and gas producers in 1984 are shown in Table 1.2.

Table 1.1
Foreign Majors: Revenues, Assets and COR 1984

	Revenues	Assets	COR
	($billions)		(%)
Imperial Oil	8.5	8.8	26
Texaco Canada Inc.*	6.2	3.4	10
Shell Canada Ltd	5.7	5.8	20
Gulf Canada Ltd.**	5.3	5.6	26
Total Petroleum	2.9	1.3	0
Amoco Canada	1.6	2.1	0
Suncor Inc	1.6	2.4	25
Mobil Oil Canada Ltd	1.6	1.7	0
Chevron Canada Ltd. **	0.8	0.7	0
Total	34.2	31.8	

* During 1985, Canadian ownership increased to 22%.
** During 1985, purchased by Canadian sources

Table 1.2
Canadian Majors: Revenues, Assets and COR 1984

	Revenues	Assets	COR
	($ billions)		(%)
Petro-Canada	4.9	9.1	100
Dome Petroleum Limited	2.4	7.9	not av.
Husky Oil Ltd	1.5	1.8	79
PanCanadian Petroleum Limited	1.1	2.2	79
Bow Valley Industries Ltd	0.8	1.9	77
Canterra	0.7	3.3	100

Exploration Activities
Exploration expenditures in 1984 amounted to $4.8 billion, with expenditures on Canada Lands accounting for 47% of this amount. By comparison, downstream expenditures amounted to $1 billion in 1984.

On the Canada Lands, a total of 141 exploration and development wells were drilled in 1984, compared with 9,072 wells drilled on provincial lands. Under the federal Petroleum Incentives Program (PIP), a major impetus to frontier activities, expenditures in 1984 amounted to $2.1 billion, of which some $1.6 billion were for expenses incurred on Canada Lands. During the first half of 1984 Canadian-controlled entities (individuals, corporations, etc.) accounted for 79% of expenditures on Canada Lands (including PIP contributions), or 59% of expenditures net of PIP contributions. Following an announcement by the federal government in October 1985, PIPs are being discontinued and are to be replaced with an exploration tax credit.

A small number of companies are engaged as operators in frontier oil activities. These operations are dominated by larger, well-financed companies that are able to provide the large amounts of funds required over long periods for these expensive operations. As such, the bulk of R&D undertaken in these areas is performed by larger companies individually or through cooperative programs. While many smaller Canadian companies and individuals have either acreage or investment interests in the frontiers, nearly all are operators only in conventional oil and gas activities in Alberta and Saskatchewan, and virtually all are involved only in exploration and production activities. The R&D community for frontier activities, which includes firms involved in ocean-related R&D, is spread out across the country, with companies and government departments located in Victoria, Vancouver, Calgary, Edmonton, Yellowknife, Ottawa/Hull, Montreal, Halifax/Dartmouth and St. John's.

Oil sands and heavy oil R&D activities are more regionally concentrated in Alberta and Saskatchewan.

Production Activities
In 1984, the value of production of the petroleum industry amounted to $24 billion. The sources of this production are shown on Figure 1.7. As Figure 1.8 shows, about 99% of the value of oil and gas production was from Alberta, Saskatchewan and British Columbia.

Figure 1.7
Value of Production by Source, 1984

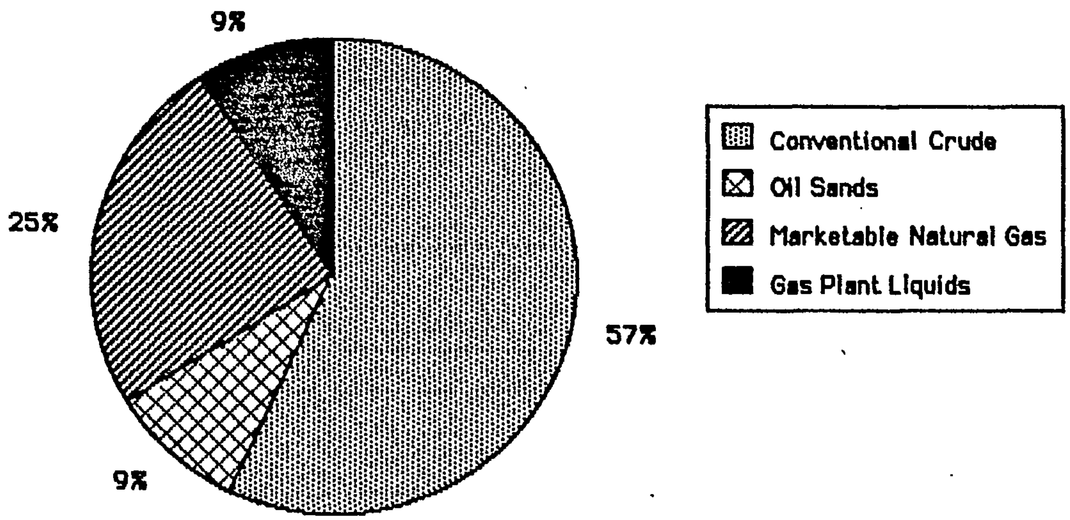
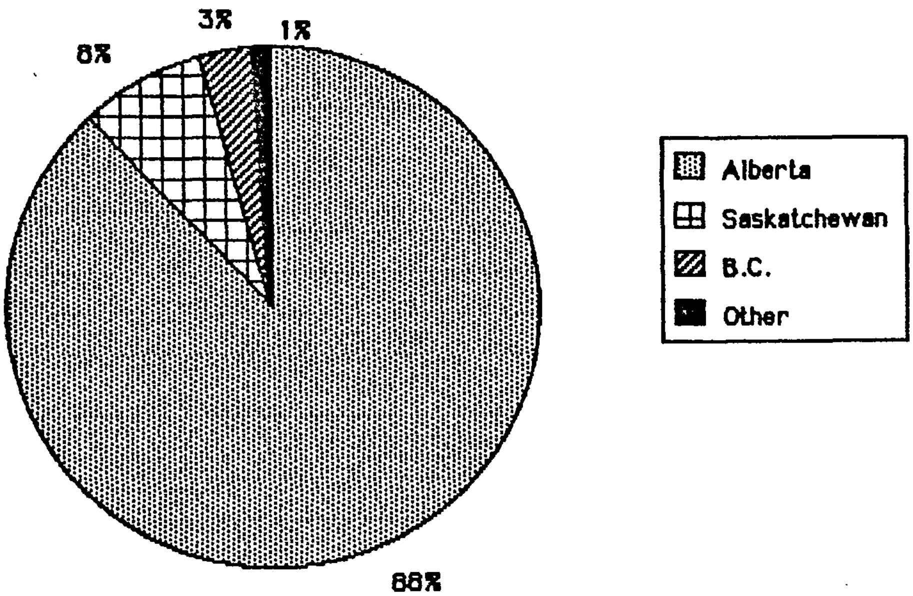


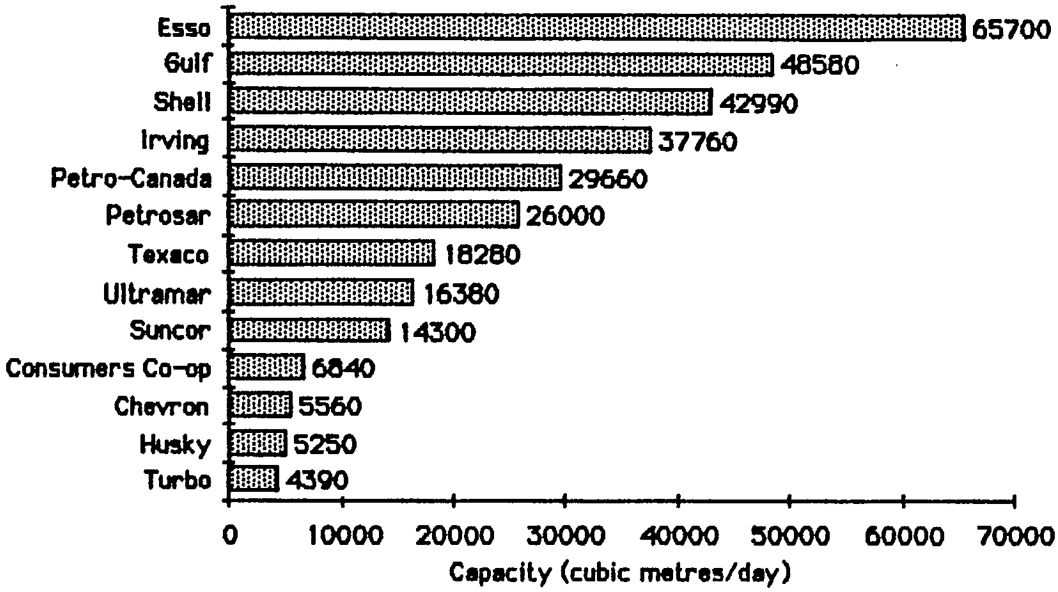
Figure 1.8
Value of Oil and Gas Production by Location, 1984



Canadian-controlled companies received $9.4 billion, or 38.8%, and foreign- controlled companies received $14.8 billion or 61.2% of the value of production.

The ten largest oil and gas liquids producers accounted for 58% of total production, with the twenty-five largest producers accounting for 78% of production.

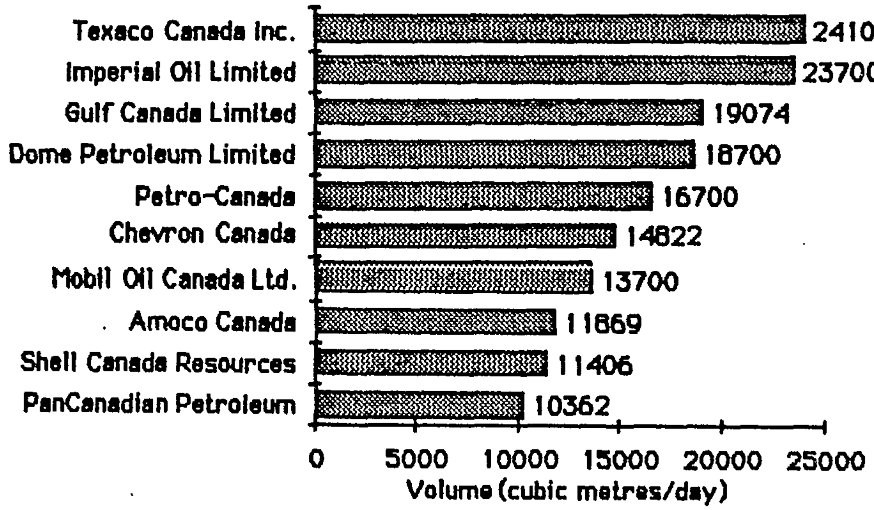
Figure 1.9
Ten Largest Oil and Gas Producers



The twenty-five largest natural gas producers accounted for 75% of gas deliveries. There is a great deal of overlap between major oil producers and major gas producers - of the 25 largest oil and liquids producers, 20 companies are among the largest producers of natural gas.

Refining
Thirteen companies are engaged in refining in Canada as shown on the following figure.

Figure 1.10
Refiners and Capacity



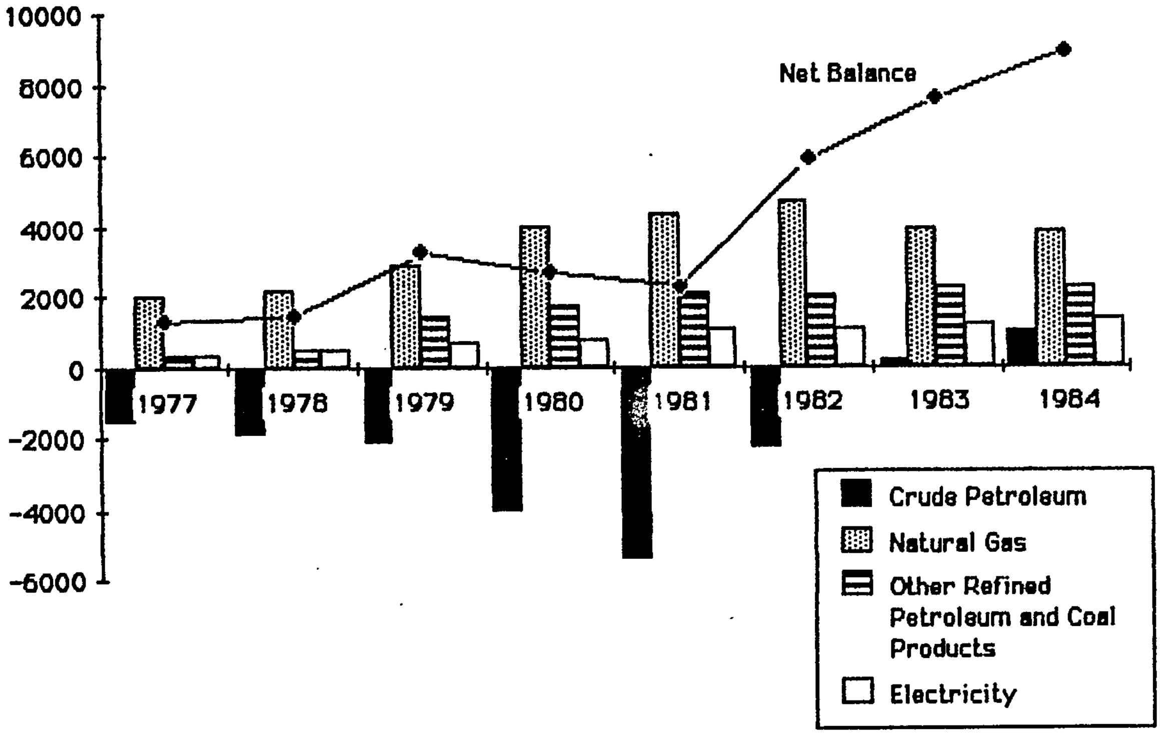
Transportation
Nearly all oil, natural gas and associated products produced in Canada are transported through a vast network of pipelines that deliver large volumes of these commodities at low unit costs. Canada has over 36,000 km of oil lines (gathering, trunk and product lines) and over 180,000 km of gas lines (gathering, transmission and distribution lines). Truck, rail and marine transport (St. Lawrence Seaway) are used for delivery of refined oil products.

Retail Operations
Over 20,000 retail products outlets operate in Canada. The six largest oil companies account for nearly 16,000 or nearly 80% of the total number of outlets. Of the total number of outlets, approximately 54% are independent stations (although most use brand names), 29% are leased, and 6% are company operated.

Employment
The oil and gas industry directly employs nearly 257,000 persons. Indirect employment by the industry amounts to an additional 146,000 and induced employment accounts for about a quarter of a million jobs.

Trade Balance
In recent years Canada's trade balance in energy has improved dramatically. Canada had a negative trade balance in crude petroleum from 1975 to 1982, when exports exceeded imports. Since then, trade balances in refined petroleum and coal products, natural gas and electricity have increased substantially as shown in the following chart.

Figure 1.11
Canada's Energy Trade Balance
($millions)



Approximately 85-90% of Canada's total energy exports are destined for U.S. markets, with nearly all hydrocarbons and products originating from the western provinces. During 1983, approximately one-third of Canadian natural gas production was sold in the United States.

During 1984, Canada's energy trade balance reached $8.8 billion, consisting of exports of natural gas amounting to nearly $3.9 billion and crude petroleum at over $1 billion, refined petroleum and coal products at $2.3 billion, and electricity amounting to $1.4 billion.

Canada exported $6 million and imported $266 million worth of oil field equipment in 1984. In 1983, where complete data are available, exports of oil field production equipment were only 2% of shipments, and imports met 55% of the total Canadian market.

Canada has had a negative technological balance of payments in the mines and wells sector in the order of $22 million (payments of $27 million and receipts of $5 million), and in petroleum products in the order of $14 million (payments of $16 million, receipts of $2 million). Technological balance of payments is defined as "*all the operations relating to the purchase and sale of technological information and know-how which are recorded in a country's balance of payments.*" While these figures are acknowledged to be only approximate, they are one "*indicator of the flow of proprietary knowledge and know-how into or from a country.*"

Summary of Financial Performance
To recap, the following trends are evident:

- Revenues increased steadily from 1980 to 1985 and declined significantly in 1986.

- Net income dropped significantly from 1980 to 1983, increased in 1984, and declined in the first six months of 1985.

- There was declining profitability in the downstream sector and rising profitability in the upstream sector until 1986.

- Cash flow declined significantly from 1980 to 1982, recovering in 1983 through to mid-1985.

- Capital expenditures increased in 1980 and have declined since 1981. Most of the declines were in the downstream sector. By the first quarter of1986, substantial declines in exploration and development capital expenditures occurred.

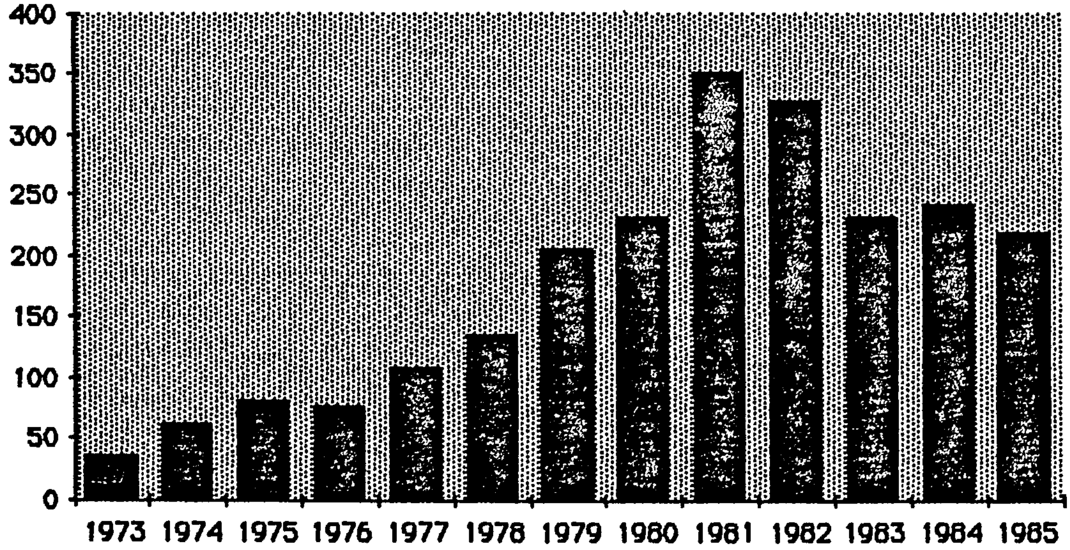
- Canadian ownership and control increased significantly from 1979 to 1984.

- Positive energy trade balances have increased greatly with the large deficit in crude petroleum shifting to a large positive balance in 1984.

Due to a combination of factors, the investment climate during the early 1980s deteriorated significantly. Government policies, in particular the National Energy Program, discouraged foreign investment, increased taxes, and reduced cash flow within the industry. High interest rates and generally poor economic conditions led to the decline of large projects, such as with oil sands plants. By 1984, however, it was apparent that the industry was recovering. More recently, drastic drops in world oil prices have had a dramatic impact on the industry, resulting in sharp reductions in expenditures and activities.

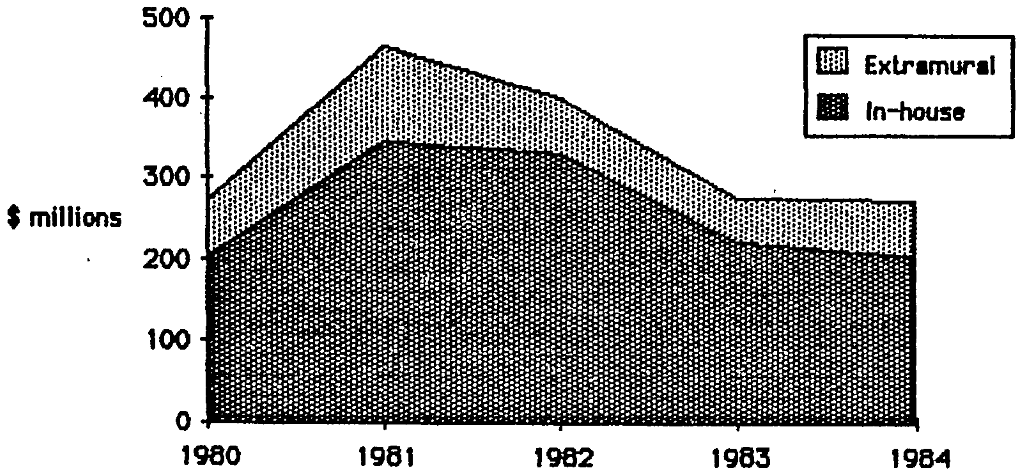
R&D PERFORMANCE
Expenditures
R&D expenditures by the petroleum industry have increased substantially since 1973.

Figure 1.12
Petroleum Industry R&D Expenditures Since 1973
($millions)



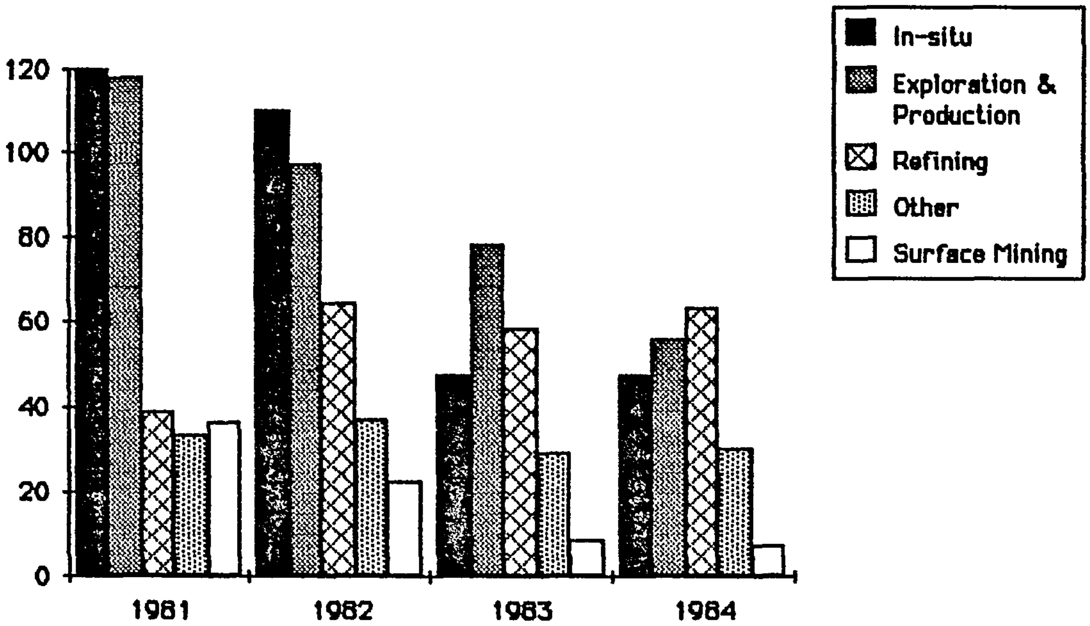
R&D expenditures of the Canadian oil and gas industry rose rapidly in 1981, but declined to 1980 levels by 1984.

Figure 1.13
R&D Expenditures, Canadian Oil and Gas Industry



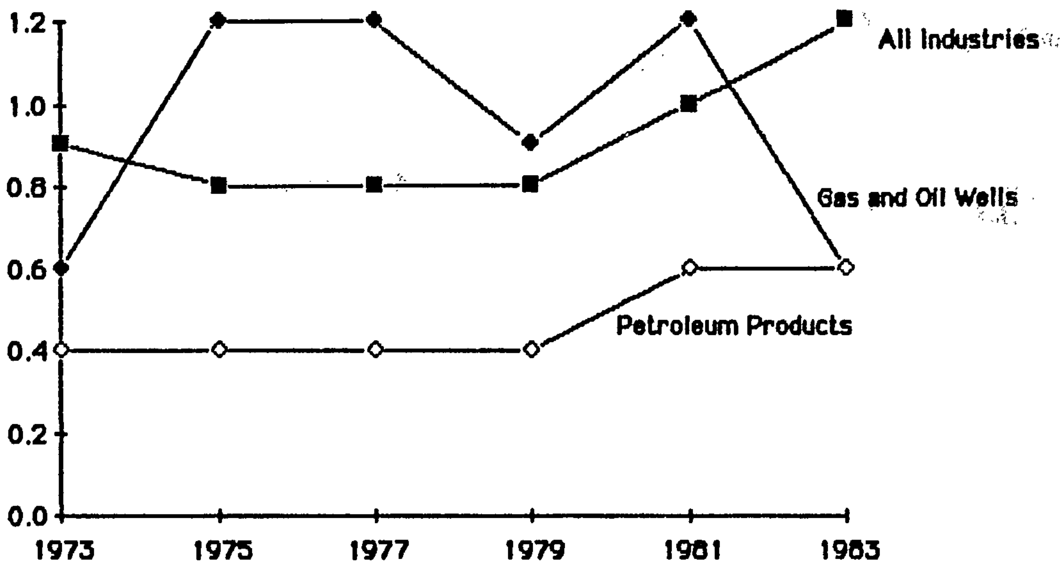
As the following chart shows, expenditures on exploration and production R&D declined by more than 50% during the period 1980 to 1984, with *in-situ* R&D expenditures declining by 60%.

Figure 1.14
Petroleum Industry In-house R&D Expenditures by Activity
($millions)



In 1982 the petroleum industry spent 1.1% of sales on in-house R&D activities, compared with the average of 1.2% of sales for all other non-financial industries. By 1983, R&D spending by the petroleum industry dropped substantially, to 0.6% of sales. By comparison, all non-financial industries had increased R&D expenditures to 1.6% of sales.

Figure 1.15
R&D Expenditures as a Percentage of Sales 1973-1983



While it is apparent that the deterioration of the investment climate was responsible for the significant drop in R&D activities, the level of R&D activities had not been responsive to the recovery of the industry.

In the upstream sector during the period 1980 to 1984, revenues increased steadily, net income and cash flow improved from 1981 onwards, and capital expenditures rose moderately. In-house R&D activities dropped substantially, however, from $274 million in 1981 to $110 million in 1984, a decrease of 60%.

While downstream revenues increased, net income in this sector was reduced dramatically, cash flow declined, and capital expenditures increased from 1980 to 1982, declining thereafter. Despite the poorer outlook for the downstream sector, R&D activities increased significantly, from $39 million in 1981 to $63 million in 1984, a 61% increase.

R&D, Foreign Ownership and Size

In 1980, the Petroleum Monitoring Agency (PMA) reported that vertically integrated companies accounted for 59% of total Canadian intramural oil and gas R&D expenditures and funded 98% of this amount from Canadian sources. The integrated companies consisted of 7 firms, 81% foreign-owned and 100% foreign-controlled. Other foreign-controlled companies accounted for 21% of intramural R&D expenditures, and Canadian corporations accounted for 20% of intramural research expenditures. Of the $67 million in extramural research expenditures made that year, $41 million was paid to parent, affiliated, and subsidiary companies. While PMA has not published comparable R&D figures by ownership, figures from 1984 reveal that some $48 million in contract R&D was purchased from parent and affiliate companies, much of it from abroad. This represented about 70% of all contract R&D spending. The remainder was paid to other corporations ($19 million) and to research institutions ($3 million).

In 1983, the oil and gas industry was about 30% Canadian-controlled, and this same category of firms performed 20% of total industry intramural R&D. This compares, however, with their performance in 1975 when only 4% of intramural R&D was conducted by Canadian-controlled firms, and Canadian control of the industry was substantially less than present levels. R&D performed by these firms in primary production of oil and gas lept from 1% in 1973 to 62% in 1983. In petroleum products, during the same period, R&D expenditures by Canadian-controlled firms remained at less than 1%, owing to the large concentration of foreign companies in the downstream sector.

Recent income-expense figures indicate that foreign-owned oil and gas firms and large integrated firms perform the largest amounts of R&D, and also have the highest ratios of R&D expenditures to revenues. The petroleum industry spent approximately $273 million on R&D activities in 1984. Some $170 million was recorded on income-expense statements. While not all R&D expenditures are accounted for in income-expense statements, the following figures indicate the comparative performance of R&D by Canadian firms with foreign firms, and by small firms with larger firms.

Table 1.3
Comparative Performance of R&D

	R&D Expenditures ($millions in 1984)	Revenues ($millions in 1984)	R&D to Revenues (%)
Canadian-controlled firms	8	22,080	.036
Foreign-controlled firms	162	42,372	.382
Integrated & refiners	137	45,429	.302
Junior oil and gas producers	6	5,837	.103
Senior oil and gas producers	27	13,186	.205

Statistics Canada reports that of 308 energy R&D performers, only 25 are engaged in R&D related to mines and wells, 168 are engaged in R&D in manufacturing and fabrication and 115 in services. In oil and gas exploration and production, only 15 companies perform R&D, and an additional 13 are involved in petroleum products R&D.

Summary of R&D Performance

A number of new R&D facilities and projects were completed in the early 1980s. Investments for many of the facilities and projects had been committed during the late 1970s - an era of mega-projects, rapid economic growth and rising oil prices. While the oil and gas industry has improved its performance since the downturn experienced in the early 1980s, R&D investments, with the exception of refining, have not improved. Rather, R&D levels have declined substantially, especially in the upstream sector.

Foreign ownership in itself does not reduce R&D activity levels in the oil and gas industry. Rather, on a R&D/revenues basis, foreign-controlled companies outperform Canadian-controlled firms. Activity levels appear to depend primarily on the ownership and size of the companies. Canadian-controlled companies have dramatically increased their performance levels in upstream R&D, with little improvement being made in the downstream sector, owing to the large foreign presence. A notable exception is Petro-Canada, which has in recent years been involved in refining R&D.

In the present "retrenchment mode" of the industry, associated with lower prices, further declines in exploration and production R&D are expected. This is of particular concern as it is the upstream sector that will discover and extract new supplies of oil and gas to meet Canada's future energy demand.

2. TRENDS FOR THE OIL AND GAS INDUSTRY

Canada's Oil and Gas Supply and Demand

During the period 1983 to 2005, Canadian energy demand has been forecasted to increase by about 43%. In 1983, oil and gas met 68% of all domestic demand; this is expected to decline to 61% by the year 2005. Market demand for natural gas is predicted to increase from 25% of total energy demand in 1983 to 31% of total energy demand by 2005.

While natural gas, natural gas liquids, and coal are in abundant supply in Canada, supplies of light crude oil are the least secure of all energy sources. Meeting Canada's future demand for oil will require either increased imports or production from the frontiers, oil sands, and heavy oil reservoirs. These domestic sources are costly, difficult to extract, and will require new technologies.

Future hydrocarbon supply and demand will depend on a host of factors, including the availability of supplies (based on geology), energy policies, conservation, investment decisions, domestic and world prices of oil, and the growth of the economy. While accurate prediction of the effects of each of these factors on actual supply and demand is difficult, if not impossible, the following factors and trends are apparent:

- Canada has abundant supplies of oil and gas in the frontiers and the oil sands. The extent of oil sands resources are well known. The amounts of commercial resources in the frontiers are, by comparison, much less certain. Development of these resources are predicated on sufficiently high prices.

- Energy policies are expected to continue to promote the exploration and production of frontier oil and the production from oil sands, in order that Canada has assured future oil supplies. Recognition will continue to be given to the long lead-times (in some cases, ten years or more) involved in bringing new oil supplies onstream from the frontiers and oil sands.

- Development projects are very sensitive to oil prices. Oil prices have declined substantially. The uncertainty of prices makes long-term planning extremely difficult. Supply disruptions from the Middle East are possible and can dramatically affect prices. Canada, along with most other nations, has in recent years reduced its dependence on less stable sources of oil.

- Growth in Gross National Product will be moderate (slightly more than 3%).

- Conservation measures in response to higher oil prices have resulted in improved energy efficiencies, substitution of oil by natural gas, and other factors will continue to reduce demands for oil.

- Investments will be spread among conventional oil, enhanced recovery, oil sands, and frontier areas. Industry will, however, find frontier development to be an increasingly attractive investment compared with conventional producing areas. Costs of finding new oil reserves in Western Canada have risen and will continue to rise significantly. For instance, from 1960 to 1979 the costs of booked reserves of crude oil in 1983 dollars have increased from nearly $20 per cubic metre ($3.10/bbl.) to over $63 per cubic metre ($10.15/bbl.). Costs of finding oil from the frontiers are becoming more attractive by comparison.

- Natural gas will continue to be provided primarily from Western Canada. Contributions to supply from the frontiers will not be significant until at least the mid-1990s.

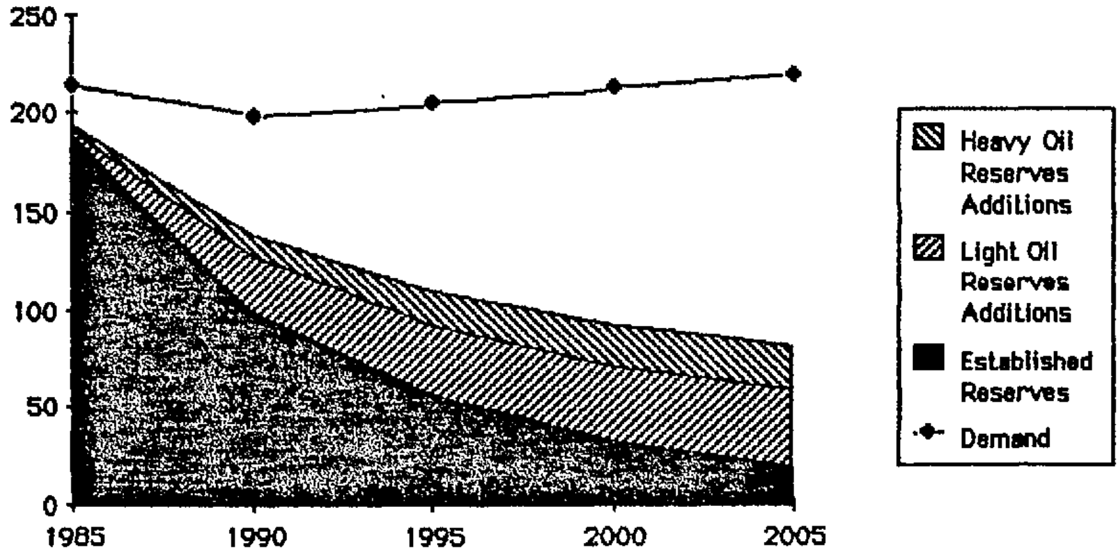
Canadian Oil Supply and Demand

Canadian oil production in 1985 was about 264,000 cubic metres per day. As domestic consumption amounts to 230,000 cubic metres per day, the country has a 34,000 cubic metre per day surplus of oil. Demand for oil is expected to decline from present levels to 200,000 cubic metres/day during the 1990s and will increase to about 220,000 cubic metres/day by 2005.

Canada presently relies heavily on conventional oil from the Western Canada Sedimentary Basin to meet its oil requirements. The rate of new discoveries has been declining from this region, which is now in a mature stage of development.

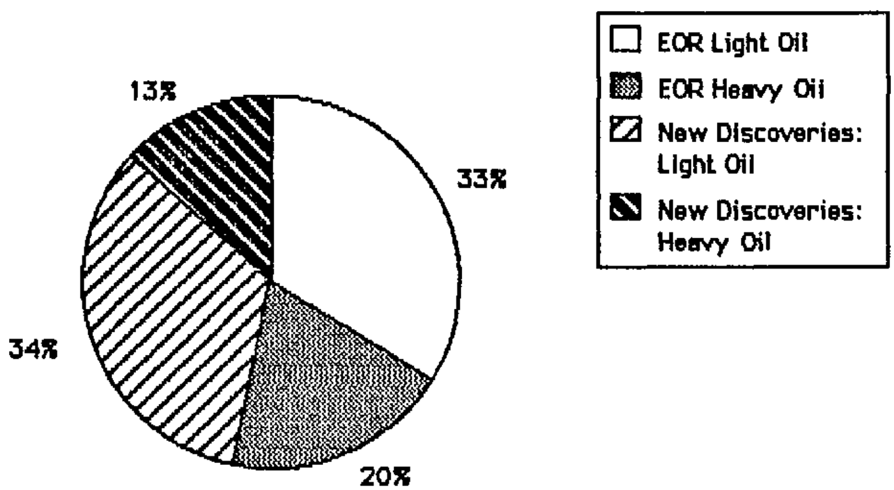
The contribution of established oil reserves to meet demand is expected to drop significantly, from 200,000 cubic metres per day in 1983 to 19,000 cubic metres per day, or about 10% of 1983 levels by 2005. Reserves additions to conventional sources by 2005 will amount to some 62,000 cubic metres per day, supplying a total of about 81,000 cubic metres per day. By 2005, demand is forecasted to be 220,000 cubic metres per day. If only conventional sources from conventional areas are to be used, supplying approximately 80,000 cubic metres per day, a shortfall of about 140,000 cubic metres per day of crude oil would result.

Figure 2.1
Forecast of Productive Capacity of
Conventional Oil and Heavy Oil Additions
from Conventional Areas
(thousands of cubic metres per day)



During this period reserves additions are forecasted to amount to 680 million cubic metres from enhanced oil recovery (EOR) and from new discoveries. These reserve additions will translate to productive capacity of 62,000 cubic metres per day by 2005.

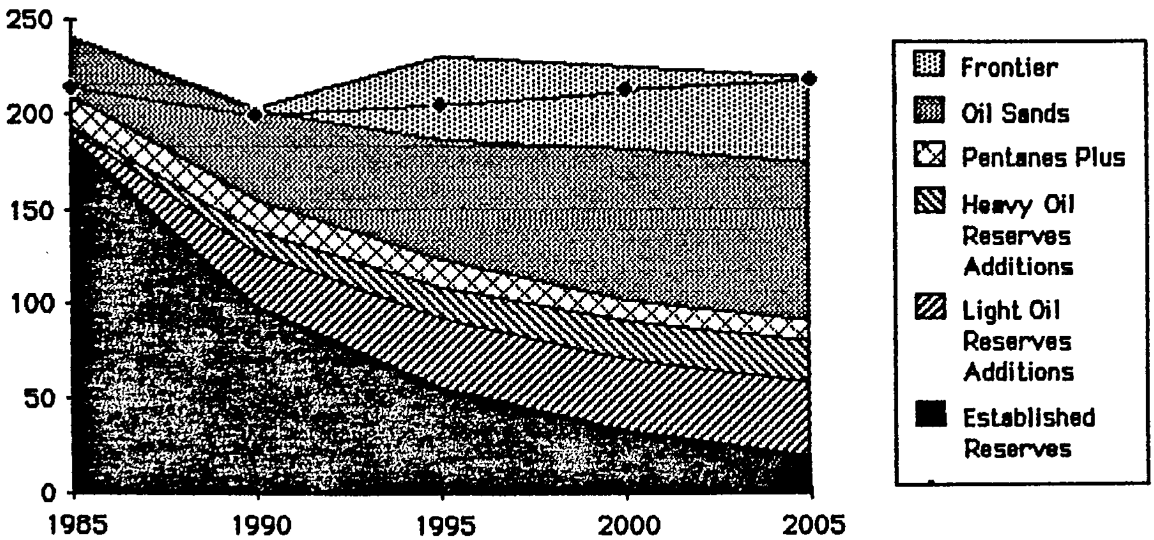
Figure 2.2
Forecast of Productive Capacity of
Conventional Oil by Year 2005



As Figure 2.2 shows, enhanced recovery will account for over half of the reserves additions to conventional oil by the year 2005.

To meet the shortfall between demand and supplies from conventional areas will require increased production from oil sands and/or development of frontier resources. These sources are expected to provide an additional 136,000 cubic metres per day by 2005. With the combination of conventional reserves and contributions from other sources, a total productive capacity of 216,600 cubic metres/day would result. Total productive capacity in thousands of cubic metres per day has been forecasted to follow the trend indicated in the following figure.

Figure 2.3
Forecast of Productive Capacity of Oil



Supplies of light and medium crudes are expected to exceed domestic requirements until the late 1990s, after which requirements would exceed supply.

Development of oil from oil sands, enhanced oil recovery, and the frontiers is essential to meet Canada's demand if imports are to be minimized. At present, there is no production from the frontiers, yet this area is expected to contribute nearly 30% of total domestic light oil production in 2005. Oil sands, while now providing less than 15% of oil production, are expected to meet about 40% of Canada's oil production in 2005. The trend for heavy crude oil is for supply to exceed demand during the next 20 years. This excess capacity supply, reaching 36,600 cubic metres per day by 2005, would be available for upgrading and export.

Although the ultimate potential of oil from the frontier regions is very large (some 87% of total Canadian ultimate potential), these areas contribute a comparatively small amount (32%) to Canada's total remaining reserves and discovered resources. If remaining established reserves alone are considered, the frontier regions contribute only about 15% of Canada's total remaining established reserves. The principal reason for this disparity is the maturity of the regions. The Western Canadian Sedimentary Basin has been relatively well-explored. By comparison, few wells have been drilled in the frontier regions and estimates of petroleum in place are speculative. Also, as most frontier discoveries have limited access to markets, they have not been classified as established reserves. A comparison of potential with remaining reserves and discovered resources for conventional oil is shown on the following figures. (Conventional oil excludes oil sands).

Figure 2.4
Conventional Oil Potential

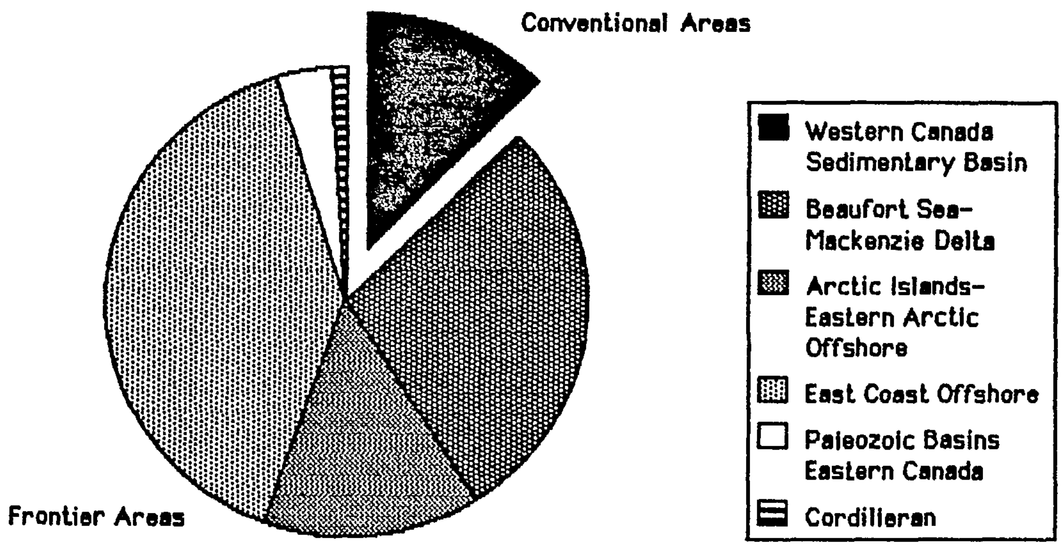
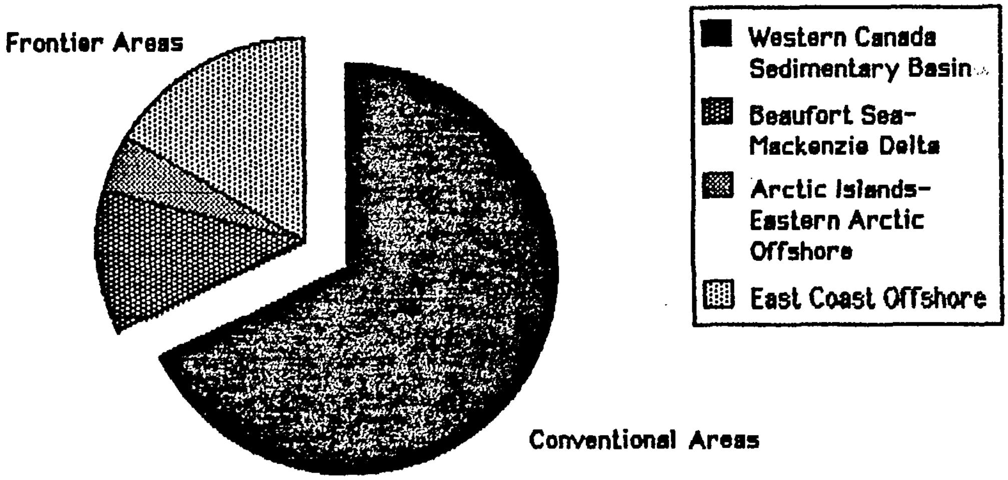


Figure 2.5
Remaining Reserves and Discovered Resources, Conventional Oil

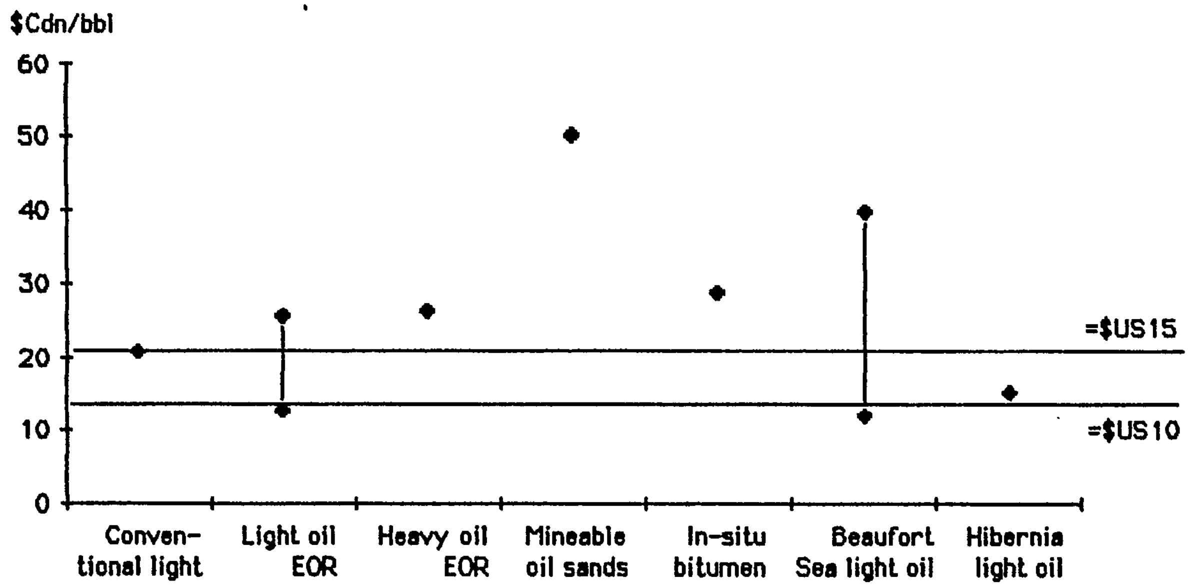


Canada also has very large supplies of non-conventional oil and gas. Quantities of crude bitumen contained within the oil sands have been estimated to be in the order of nearly 200,000 million cubic metres. Established remaining reserves of synthetic crude oil are estimated at approximately 3,860 million cubic metres. Total amount of heavy oil in-place is in the order of 7,500 million cubic metres. Other resources, such as carbonate oil and oil shale may also be developed.

Development of conventional and non-conventional oil resources will depend on numerous factors, including technological development and economic conditions; in particular, the relative costs of oil produced from various sources, and world oil prices are important.

Comparative social supply costs (SSC) have been estimated according to oil supply by source. The Economic Council of Canada defines social costs as being "the total costs to industry before any payments to government and any receipt (subsidy) from government", and are measured in constant dollars per unit of supply. The social supply costs figures and comparative world oil prices are shown in the following chart.

Figure 2.6
Social Supply Costs (ECC)

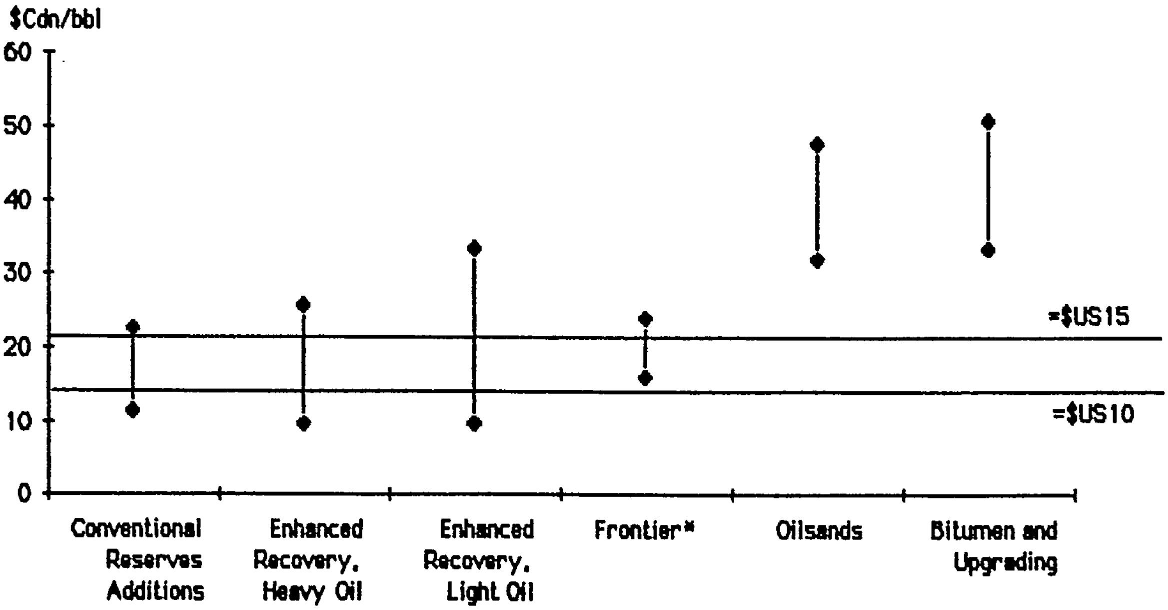


See sources for discussion of assumptions.

The Economic Council of Canada notes that the profitability of Western Canada conventional light oil is low, and that frontier areas have potentially good profitability, but risks are high.

The National Energy Board (NEB) has also provided estimates of oil prices and social supply costs, illustrated in the following figure.

Figure 2.7
Social Supply Costs (NEB)



*Excluding transportation of $10-80 / cubic metre. See sources.

With the social supply costs shown, these sources are not likely to be developed at the present level of world oil prices. The previous forecasts of productive capacity from new sources are therefore questionable.

Comparing Canadian reserves and production costs with those of other countries clearly demonstrates the difficulties Canada will face with lower oil prices and world-wide surpluses.

Figure 2.8
Comparative World Oil Reserves
(billions of barrels)

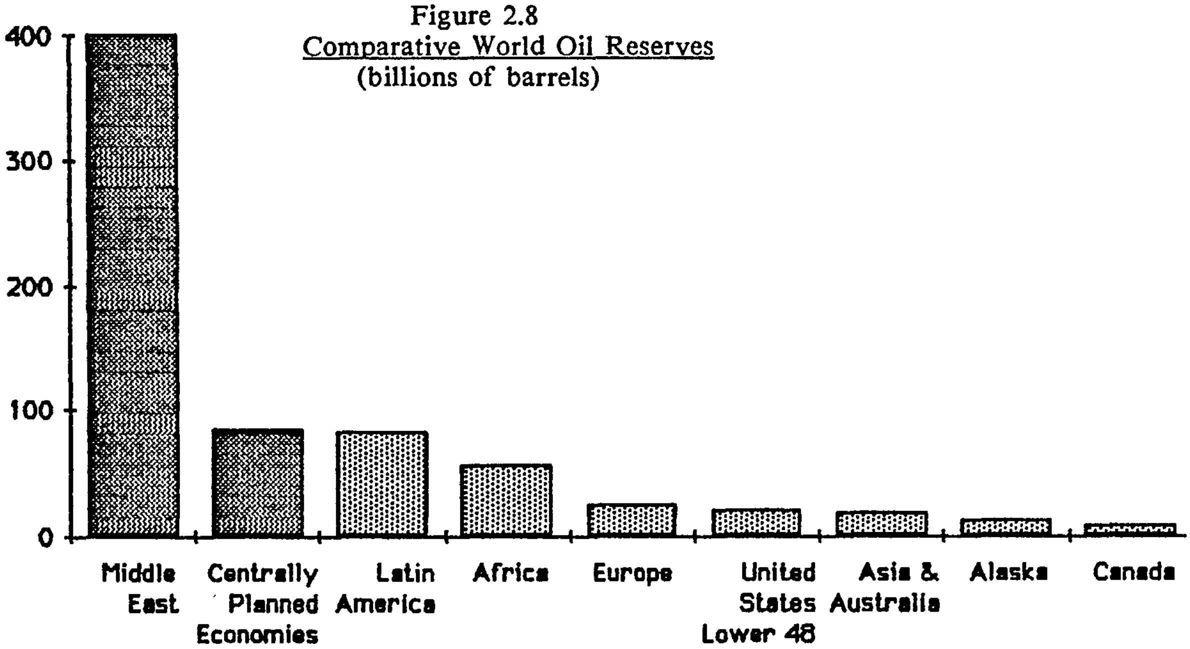
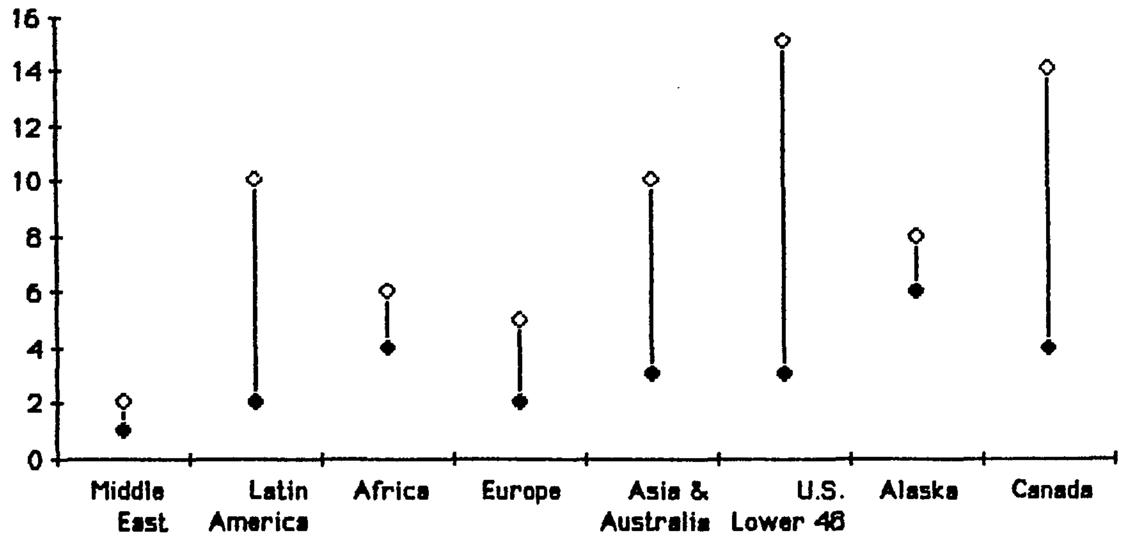


Figure 2.9
Comparative World Oil Production Costs
($US/bbl)



In terms of primary domestic oil demand by product, the following trends are anticipated:

Table 2.1
Forecasted Primary Oil Demand by Product

	% 1983	% 2005
Motor Gasoline	38	33
Diesel Fuel Oil	18	27
Light Fuel Oil and Kerosene	12	5
Other	11	13
Aviation Fuel	5	7
Asphalt	4	5
Heavy Fuel Oil	12	10
Total	100	100

As can be seen, there will be significant increases in diesel fuel oil use, relative declines in motor gasoline, and a significant drop in the use of light fuel oils and kerosene.

Natural Gas Supply and Demand
Recent figures for natural gas indicate that Canada has sales of 211.2 million cubic metres per day, of which 77 million cubic metres per day was exported. Demand for natural gas is expected to increase substantially in the next 20 years as it enters new markets and displaces oil usage.

Supplies of natural gas will continue to come primarily from Western Canada, where established reserves are approximately 30 times current annual production. By 2005, East Coast offshore and Arctic regions are expected to supply some 15% of total natural gas demand. Canada has significant potential of natural gas, largely located in frontier regions as shown on the following figures.

Figure 2.10
Natural Gas Potential

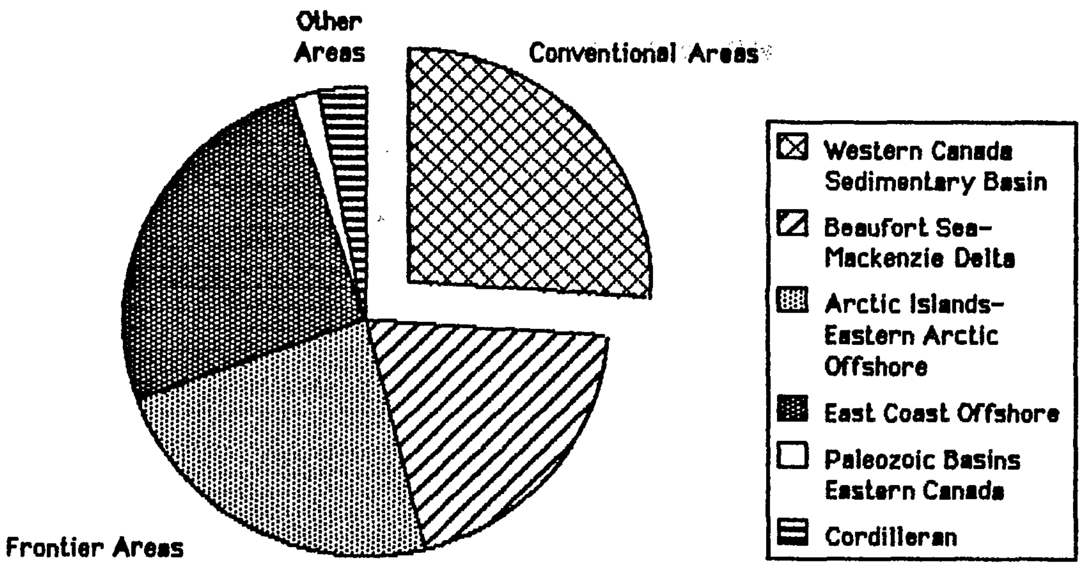
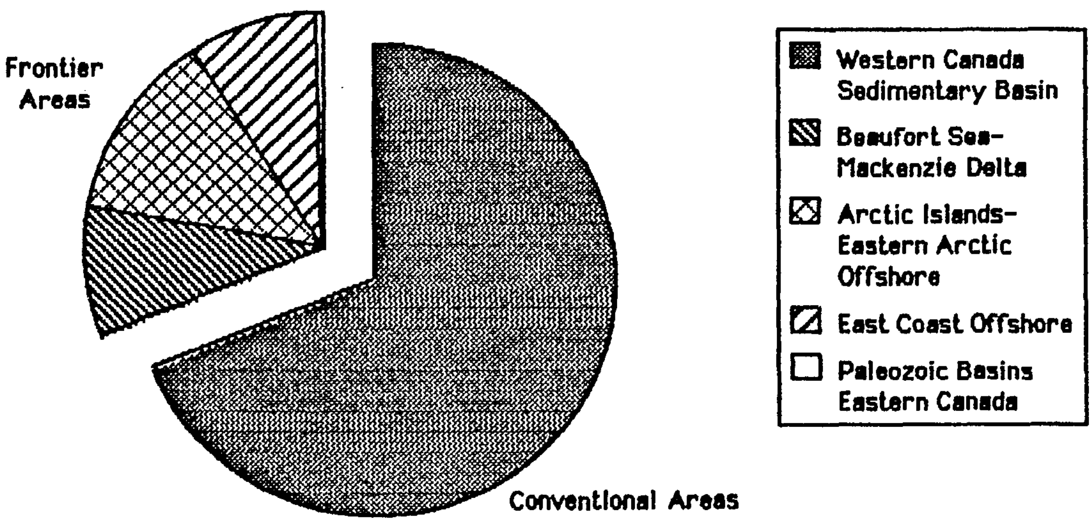


Figure 2.11
Remaining Reserves and Discovered Resources of Natural Gas



The estimated social supply cost for natural gas from Western Canada is about $65 per thousand cubic metres, and about $135 per thousand cubic metres from the offshore Venture field. While significant quantities of natural gas exist in the frontiers, a substantial surplus of comparatively inexpensive gas exists in Western Canada. Pipeline and liquefied natural gas (LNG) tankers have been proposed as transportation systems to bring frontier gas to markets, but these projects have been deferred until markets exist for this expensive source of natural gas. Anticipated trends in natural gas usage include:

- end use demand growth of 3.5% per year in the 1980s, and 2.5% in the 1990s,
- declines in use for thermal electricity generation,
- increased use as a vehicle fuel,
- significant increased use as a petrochemical feedstock (from 233 petajoules in 1983 to 372 petajoules by 2005).

Natural Gas Liquids

Natural gas liquids (NGLs) including ethane, propane, butanes and pentanes plus, are by-products obtained during natural gas processing and oil refining. At present, natural gas plants provide all ethane and pentanes plus, and the majority of propane and butanes. A few of the uses of NGLs are:

- ethane is a key feedstock for the petrochemical industry,
- butanes are used for blending in gasoline,
- ethane and propane find use as injection fluids for EOR,
- pentanes plus are used as a viscosity reducing agent in the pipeline transport of heavy crude oils.

Demand for natural gas liquids is forecasted to rise significantly in the next 20 years.

Table 2.2
Demand for NGLs

	1983	2005
	(thousand cubic metres/day)	
Ethane	5.9	17.2
Propane	10.5	14.3
Butanes	5.2	7.2

Supplies are expected to exceed requirements, with the balance being available for export.

Strengths and Outlook
Canada has many strengths in the development of its oil and gas potential, including:

- large reserves of oil and gas, and large potential of hydrocarbons
- a strong and viable oil and gas industry,
- well-educated and trained professionals,
- expertise in operating in cold, remote offshore regions,
- expertise in extracting heavy oils and oil from the oil sands.

As production from mature, conventional areas declines, these strengths will become increasingly important. Development of Canada's future supplies of oil and natural gas will require substantial increases in production from frontier regions, the oil sands, and from heavy oil through enhanced oil recovery processes. Oil sands and frontier oil have been projected to provide large portion of total light crude oil supply by 2005. In recent years these two sources supply less than 15% - entirely from oil sands. Enhanced oil recovery will account for over half of reserves additions in conventional areas in the next twenty years. These projections require sufficiently high oil prices. With present prices, many of the projects to develop these resources are now in question.

Oil from the frontiers, oil sands, and enhanced oil recovery all require sophisticated and in certain cases, new technologies. As such, R&D will be essential to ensuring domestic oil security, and could increase Canada's energy trade surplus through cost-effective development of oil, natural gas, and refined products.

3. GOVERNMENT POLICIES AND PROGRAMS

The federal and provincial governments have established a wide variety of policies, agreements, and programs that have both direct and indirect effects on R&D and technology development in the oil and gas industry. Policies, regulations, and fiscal regimes provide the environment in which the industry operates, which in large measure determines the pace and location of industry's activities. The level of industry's activity and the location of this activity in turn are the driving forces determining the level and type of R&D activity being conducted. Government policies and programs are also utilized as a means of promoting technology development.

Jurisdiction

While Canada has jurisdiction over petroleum resources beneath the continental shelves, the federal government has established joint management and revenue-sharing arrangements with the provinces of Nova Scotia and Newfoundland. In the Northwest Territories, the federal and territorial governments cooperate on the management of oil and gas activities. The provinces hold all onshore sub-surface mineral rights, with the exception of small amounts of freehold lands. As oil sands and heavy oils are within Alberta and Saskatchewan, government policies, programs, and support for R&D are predominantly the responsibility of the provinces.

About 300 federal government policies and programs administered by 17 federal departments, directly or indirectly affect offshore oil and gas activities. These policies and programs are in the areas of incentives and taxes, regulations and licensing, common user services, data and information resources, and advisory services.

FEDERAL POLICIES AND PROGRAMS

Federal policies and federal-provincial agreements relevant to offshore energy development and R&D activities include the *Frontier Energy Policy*, the *Atlantic Accord*, the *Canada-Nova Scotia Oil and Gas Agreement*, the *Western Accord*, and *Canada's Oceans Policy*. The *Regional Economic Development Intergovernmental Position Paper* has less direct importance to energy development, but is significant in its emphasis on regional decision-making and regional economic growth.

Frontier Energy Policy

The *Frontier Energy Policy*, announced on October 30, 1985, and associated provisions in the Western and Atlantic Accords have replaced many of the provisions of the *National Energy Program* (NEP). Significant features of the *Frontier Energy Policy* include:

- establishment of the *Canada Petroleum Resources Act*, replacing the *Canada Oil and Gas Act*,

- creation of a 25% exploration tax credit (refundable at a 40% rate), replacing the *Petroleum Incentives Program*,

- availability of a 25% investment royalty credit for frontier exploration well costs for wells costing $5 million or less,

- a royalty regime that limits royalties during the early years of production,

- a competitive system for allocation of exploration rights,

- a fixed term not exceeding 9 years to be included in all Exploration Licenses, after which lands will be surrendered, except for hydrocarbon discovery areas,

- requirement for a 50% Canadian ownership level at production for discoveries made after March 1982,

- no preferential treatment of Petro-Canada,

- removal of the 25% Crown share provision.

Themes associated with the *Frontier Energy Policy* include: establishment of a stable management system, a profit-sensitive royalty regime, fair Canadianization requirements, encouragement of investment, provision of jobs, use of energy as an "engine for economic growth", and promotion of energy self-sufficiency.

The Atlantic Accord

The *Atlantic Accord*, signed February 11, 1985, is an agreement between the federal and Newfoundland governments. Key provisions of the Accord include:

- joint management of offshore oil and gas resources and sharing of revenues,

- establishment of the Canada-Newfoundland Offshore Petroleum Resources Board,

- division of decisions on offshore resources among the two governments and the Board,

- sharing of revenues based on the principle that revenues will be treated the same as if on land in other provinces,

- establishment of a development fund of $300 million over 5 years to be funded by the federal ($225 million) and provincial ($75 million) governments,

- provision of benefits plans for each work program to ensure the employment of Canadians and, in particular, provincial residents, and also to ensure that Newfoundland and Canadian companies have a full and fair opportunity to participate in the supply of goods and services,

- provision of expenditures to be made on R&D and education and training through the benefits plans,

- continuation of the Environmental Studies Revolving Funds (ESRF), with the application of levies in the Newfoundland offshore being subject to the Board's approval.

The Canada-Newfoundland Offshore Petroleum Board has the primary responsibility for implementing provisions of the Atlantic Accord dealing with the management of oil and gas activities. The Board consists of seven members: three members appointed from each government and the chairman is appointed jointly by both governments. In its review of benefits plans, the Board is instructed to ensure that first consideration is given to Newfoundland suppliers. As well, benefits plans submitted by oil company operators must make provisions for expenditures in Newfoundland on research and development, education, and training. The Accord defines which decisions will be made by each government and the Board.

The Offshore Development Fund is designed to defray infrastructure costs related to the development of oil and gas before production commences. Ministers from both governments may propose projects for funding. A Development Fund Committee comprised of two representatives from each government will be established to monitor and review the implementation of the Fund. The fund will be *"used to create economic activity by building roads, supply bases and training and manufacturing facilities needed for offshore development."*

Canada-Newfoundland Ocean Industry Sub-Agreement

The five-year *Canada/Newfoundland Ocean Industry Development Subsidiary Agreement* of1984 was formulated under an Economic and Regional Development Agreement (ERDA). The objective of the Agreement is:

> *"to encourage Newfoundland businesses and communities to fully exploit the industrial R&D and supply opportunities arising from offshore mineral developments, the fishery and marine transportation, thereby maximizing the employment and income benefits to Newfoundland, and Canada as a whole, with respect to ocean industries."*

The Agreement has been designed to encourage medium and high technology-based activities and to facilitate the growth of the province's ocean scientific base through applied research, innovation, and technology transfer. As well, emphasis is given to promoting market penetration of new and existing ocean industries.

A *Memorandum of Understanding Regarding Science and Technology Between Canada and Newfoundland* as a sub-agreement of the ERDA was signed on April 23, 1986. Elements of the Memorandum include achieving the objectives of harmonization of activities to improve the competitivenss of traditional resource-based industries, development of new products, services, and knowledge-intensive industries and to increase Newfoundland's capability for technological development, innovation and diffusion. The strategy agreed to consists of identification of needs and requirements in areas where S&T are relevant to Newfoundland's priorities and opportunities for economic and regional development. To implement the strategy, the Memorandum calls for establishment of a Canada/Newfoundland Science and Technology Committee.

Canada-Nova Scotia Sub-Agreement
Canada and Nova Scotia signed the *Subsidiary Agreement on Ocean Industry Development* on July 24, 1981. The two stated objectives of the Agreement were: to encourage the growth of medium to high technology ocean manufacturing and service industries; and to "*support applied research and technology transfer which will enable Nova Scotia to capitalize on its existing ocean scientific base to become a true centre of excellence in the ocean industries sector.*" In July 1985, a *Technology Transfer and Industrial Innovation Agreement* was concluded under an Economic and Regional Development Agreement (ERDA). The objectives of the Agreement are:

- to provide support to Nova Scotia as a centre of engineering and scientific excellence,

- to revitalize existing industry through advanced technology and processes, and

- to increase the application of the results of applied research for industrial uses.

Canada-Nova Scotia Resource Agreement
The *Canada-Nova Scotia Agreement on Offshore Oil and Gas Resource Management and Revenue Sharing* was signed on March 2, 1982. The Agreement was subsequently enacted in legislation in June 1984 by both governments. Some of the provisions of the Canada-Nova Scotia Agreement are:

- establishment of the Canada-Nova Scotia Offshore Oil and Gas Board,

- agreement that resource revenues will flow to the government of Nova Scotia as if resources were on land, until such time as certain fiscal levels are exceeded,

- creation of the Canada-Nova Scotia Development Fund,

- establishment of two additional funds, Education and Training, and Research and Development.

The Canada-Nova Scotia Offshore Oil and Gas Board is chaired by the

Administrator of COGLA and is comprised of two members appointed by Nova Scotia and two members appointed by the Government of Canada. The Board reviews and recommends approval to the appropriate minister on all aspects of offshore oil and gas activities, approval of exploration agreements and Canada Benefits plans, environmental and safety aspects of drilling programs, and development and production plans. In the review of Canada benefits plans first consideration is given to services and goods supplied from Nova Scotia, although goods and services must be competitive in terms of price, quality and delivery.

The Development Fund, in the amount of $200 million, is designed to defray infrastructure costs related to offshore hydrocarbon activity. The federal government advances funds up to $50 million per year, the amount depending on approved project proposals. The province will repay these advances from offshore production.

Western Accord

The *Western Accord* , announced in March 1985, removed numerous special taxes, subsidies and regulations previously contained in the *National Energy Program*. The Accord was signed by the federal government and the Alberta, British Columbia and Saskatchewan provincial governments. Major elements of the Accord are:

- deregulated prices for oil,

- allowance for negotiation of sales contracts betwen oil producers and purchasers for foreign or domestic oil,

- control of exports if security of supply is a problem; with longer term exports requiring National Energy Board and Cabinet approval,

- phasing out of the Petroleum and Gas Revenue Tax (PGRT) and the *Petroleum Incentives Program* (PIP). The PGRT is a tax on production revenue, and the PIP is an incentive program for exploration. As PGRT is phased out, taxes will be based on profits, as in other industries.

- elimination of the Natural Gas and Gas Liquids Tax, the Incremental Oil Revenue Tax, the Canadian Ownership Special Charge, the Crude Oil Export Charge, and the Petroleum Compensation Charge.

- allowance for adjustments by provinces to royalty and incentive systems provided that industry continues to benefit from the decontrol changes contained in the Accord,

- a more flexible, market-oriented natural gas pricing mechanism.

One result of the removal of the PGRT would be increased cash flow for the industry, estimated to be in the order of $3 billion. Governments expected the industry to reinvest this increased cash flow to encourage economic growth.

The National Energy Program

The *Western Accord*, the *Atlantic Accord*, and the *Frontier Energy Policy* have removed many of the provisions of the *National Energy Program* (NEP). Consideration of the NEP is important, however, for at least two reasons. Firstly, certain broad goals of the NEP have been maintained, although specific methods to achieve the goals have been eliminated. Secondly, the NEP has had a direct and lasting effect on industry activities, such as the increased activities in the frontier regions. The NEP had three stated goals:

- To establish the basis for Canadians to seize control of their own energy future through security of supply and ultimate independence from the world market;

- To share in the benefits of industry expansion; to establish a petroleum pricing and revenue-sharing regime that recognizes the requirement of fairness to all Canadians no matter where they live; and

- To offer to all Canadians the real opportunity to participate in the energy industry in general and the petroleum industry in particular.

The first objective, security of supply, was to be achieved through various measures to encourage exploration and production, and to reduce consumption through conservation and oil substitution programs. The pricing and revenue-sharing regime involved a complex system of new taxes and prices. A Canadianization program was pursued through the *Petroleum Incentives Program* (PIP) and through other measures designed to meet the goals of attaining at least 50% Canadian ownership of production by 1990, increasing the share of the industry owned by the Government of Canada, and increasing Canadian control of larger oil and gas companies. By early 1982 high interest rates, the recession, and softening demand for oil reduced industry's cash flow and profits, requiring revision of the NEP by governments adjusting their share of petroleum revenues.

The reaction to the NEP of the Alberta government and many companies in the oil and gas industry was strongly negative. The reaction by the oil and gas industry, while not uniform, consisted of several themes, including:

- Companies stated that the limitations on price increases and the additional taxes resulted in inadequate netbacks to companies and restricted the amount of capital available for exploration.

- Foreign-owned firms reduced exploration budgets significantly.

- Foreign-owned firms were critical of the Crown interest provision, the discrimination in favour of Canadian firms receiving incentives, and the expansion of Petro-Canada. The 25% Crown interest was seen as confiscatory by most firms.

- Larger Canadian firms, while criticizing elements of the NEP, responded favourably to the opportunity to expand, and were supported by banks in takeovers of other firms.

- Some smaller Canadian firms opposed the NEP on ideological grounds and because of the reductions in cash flow caused by the Program.

- An increase in activity in offshore activities resulted from PIPs, with greater Canadian participation.

The Alberta government vigorously opposed the NEP, primarily in the areas of pricing, revenue-sharing and resource management.

Canada's Oceans Policy
Canada's Oceans Policy was announced by the Minister of State for Science and Technology (MOSST) in 1973. Significant elements of the Policy are that:

- *"Canada stimulate development and effective participation of Canadian industry in the plan to see that Canada controls the essential industrial and technological ingredients to exploit offshore resources.*

- *Special emphasis be given to a wide range of marine science and technology programs relating to management of the marine environment, renewable and non-renewable resources, development and maintenance of ocean engineering at universities and in government laboratories and better forecasting of weather, currents, ice and similar atmospheric and oceanic factors.*

- *Canada within five years, achieve world-recognized excellence in operating on and below ice-covered waters.*

- *Canada stand equal or superior to foreign governments or large multi-national corporations in developing and maintaining a current information base about its renewable and non-renewable offshore resources."*

APPROVALS PROCESS FOR OFFSHORE OIL AND GAS

The petroleum industry's activities in the frontier regions are closely controlled and monitored through numerous government regulations and guidelines in order to ensure that operations are conducted safely, in an environmentally sound manner, and maximum benefits are secured. Before proceeding, major energy projects are subject to thorough reviews by government and the public. Final approval for major projects rests with the Cabinets in the federal, provincial and territorial governments.

The project approvals process for exploration activities on Canada Lands consists of calls for proposals, negotiation of exploration agreements, drilling program approval and the granting of authority to drill a well. Separate approvals are required for production and transportation projects. As well, environmental impact assessments are required for major projects that may have significant impacts.

In Nova Scotia, offshore resource management is handled by the Canada-Nova Scotia Petroleum Board, comprised of three federal representatives, three provincial representatives, and the chairman, who is also the Administrator of the Canada Oil and Gas Lands Administration (COGLA).

Under the provisions of the Atlantic Accord, a Canada-Newfoundland Petroleum Board was established consisting of an independent chairman and two representatives each of the federal and Newfoundland governments. The Boards in each province are supported by staff who are responsible for reviewing and assessing project approvals under the following areas: land management, safety, engineering, environmental impacts, and Canada Benefits provisions. For applications on other Canada Lands, COGLA in Ottawa handles these functions.

Project proponents must submit a Canada Benefits plan to the Boards. This plan contains items such as employment, procurement, and training. The plan may include a description of planned R&D activities. The responsible boards or COGLA review the plans in consultation with the Department of Regional Industrial Expansion (DRIE) and the Canada Employment and Immigration Commission (CEIC). In Newfoundland and Nova Scotia plans are also reviewed by the respective departments of development.

The Government of the Northwest Territories (GNWT) established its own assessment, review and monitoring process for resource development projects through its Resource Development Policy. The policy states that the GNWT "*will support development when its overall economic, social and environmental implications are judged to result in a net benefit to the people of the Northwest Territories.*" The Policy is directed primarily to the socio-economic impacts of development which are addressed through the formation of Development Impact Zones (DIZ), and DIZ groups to represent the public interest in the areas being affected by development. Project proposals are reviewed by the GNWT, with the government expecting operators to provide specific plans for employment, career counselling, training programs and where possible, utilization of NWT businesses.

Contracts over $50,000 are submitted for review to COGLA prior to bidding. COGLA, DRIE, and the provinces or territories review these pre-bid lists to ensure local and national suppliers are not excluded. This is to ensure that regional and Canadian firms have full and fair access to supply goods or services on a competitive basis. The decision to award contracts rests with oil companies. COGLA retains the right, however, to ratify these decisions. While there is no legislation or regulation governing Canadian-content in procurement, guidelines or codes of good practice are being developed and proposals are judged on their merits on a case-by-case basis. Procurement decisions are based on considerations of price, financing, delivery, and quality. Certain imported products used in offshore operations are subject to tariffs. Investment Canada, which replaced the Foreign Investment Review Agency, is taking an active approach to encourage foreign investment.

The Environmental Assessment Review Process (EARP) typically has a wide scope in its review of proposed projects and may address R&D requirements, especially when further work is required before the project can proceed in a safe and environmentally acceptable manner. For instance, the report of the Beaufort Sea Environmental Assessment Panel included several recommendations pertaining to the performance of additional work in basic research, scientific activities, and development of technologies.

Transportation of oil and gas across provincial or national borders is subject to review and approval by the National Energy Board. The Board is responsible for public interest considerations, such as economic viability and potential socio-economic and environmental impacts. Acting as a quasi-judicial tribunal and a regulatory enforcement body, the Board reviews engineering and technical aspects of pipeline operations and has the authority to license the movement of oil or gas across political boundaries.

FEDERAL GOVERNMENT FINANCIAL ASSISTANCE

In addition to the development funds and agreements described above, other general programs not specifically targetted to ocean industry or offshore oil and gas development are available in support of science and technology. Key programs are administered by the Department of Regional Industrial Expansion (DRIE), the National Research Council (NRC) and the Department of Supply and Services (DSS). In November 1985, NRC announced an increased emphasis on applied R&D that is expected to be advantageous to industry. Programs of interest for technology development in the oil and gas sector include:

Financial Assistance and Departmental Programs:

- *Industrial and Regional Development Program* (IRDP)
- *Industrial Research Assistance Program* (IRAP)
- *Program for Industry/Laboratory Projects* (PILP)

- *Industrial Energy Research and Development Program* (IERD)
- Federal Business Development Bank

Procurement:
- *Contracting-out Policy*
- *Unsolicited Proposals Program* (UPP)

Training and Assistance
- *The Canadian Jobs Strategy* program:
  1. Skill Investment
  2. Skill Shortages
  3. Job Development
  4. Job Entry
  5. Innovations
  6. Community Futures

Intellectual Property
-Canadian Patents and Development Limited (CPDL)

University/Industry Co-operative Programs
- Research Manpower Awards
- Research Grants

Scientific and Technical Information
- Canada Institute for Scientific and Technical Information (CISTI)
- *Industrial Research Assistance Program* (IRAP)

Incentives have also been provided in the Budget of May 23, 1985 for investment in research and development.

ALBERTA AND SASKATCHEWAN APPROVALS PROCESS

In Alberta, applications for oil sands projects are made through the Energy Resources Conservation Board under the *Oil Sands Conservation Act.* The approvals process requires that hearings be held, and surface rights are negotiated at that time. Each project is reviewed and assessed in detail on its individual merits. Unlike routine approvals of conventional oil projects, it may take 9 months to a year from the date of application to final approval of an oil sands project. In recent years, a moratorium on new oil sands projects has been in place in an attempt to prevent companies from tying up too many leases without adequate development. Saskatchewan's approvals process for heavy oil projects is administered through its Department of Energy and Mines.

Research in heavy oils in Saskatchewan is supported through the *Canada-Saskatchewan Agreement*, which funds EOR pilot projects in cooperation with industry. The *Canada-Saskatchewan Heavy Oil Research Program*, with a budget of $28 million between 1985 and 1988, is designed to encourage RD&D projects on heavy oil production, transportation, and processing capabilities.

IMPACTS OF POLICIES AND PROGRAMS ON R&D

The low after-tax cost of frontier exploration promoted under the *National Energy Program* led to a shift in exploration spending from conventional provincial lands to federal lands. The preferential treatment given under the NEP to Canadian-owned firms encouraged a variety of arrangements of multi-nationals and smaller Canadian-owned companies. The regulatory / approvals regime on the Canada Lands is seen by industry to be onerous, resulting in higher costs and longer delays than are considered necessary. The impact of new policies on offshore activities, without considering world oil prices, is expected to be as follows:

- Reduction of expenditures by Canadian-owned firms because of increases in costs, from $.10 to $.37 on the dollar for wholly-owned Canadian firms.

- Other considerations being equal, foreign-owned firms are expected to maintain present levels of exploration activities, as their after-tax cost remains unchanged at $.37 1/2 on the dollar.

- Increasing emphasis will be placed on production rather than exploration, in part due to a more attractive royalty regime, and the discontinuation of the carried interest of the federal government.

Increased cash flows and the potential for higher profitability levels under new energy policies were expected to lead to increased R&D activities. The major uncertainty is now with lower oil prices, which, if they persist, could have a dramatic effect on investments made in the more expensive offshore areas, oil sands, and heavy oils. Changes to existing energy policies are presently being debated, with measures such as royalty reductions, exploration incentives, a floor price, import taxes or import quotas, being suggested by some.

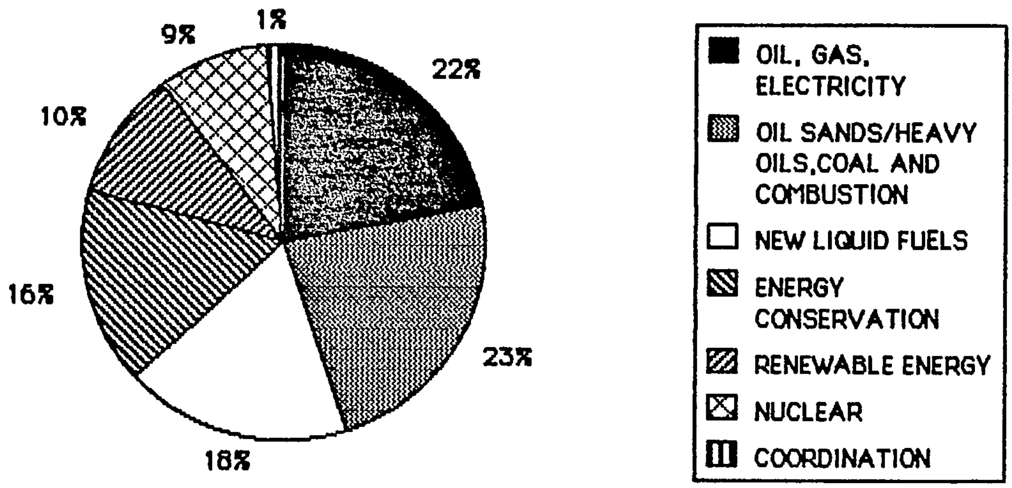
Various other policies in place encourage R&D in oil and gas research and emphasize the maximization of local and domestic benefits. A wide range of funding programs are available for oil and gas R&D. The extent to which these are used is discussed in later chapters.

4. TECHNOLOGICAL SUPPORT FOR THE OIL AND GAS INDUSTRY

Government Oil and Gas R&D Expenditures
In 1983, the federal and provincial governments' expenditures on energy research, development and demonstration (RD&D) were $480 million. Of this amount, the federal government spent 81% or about $390 million. Oil and gas related R&D accounted for 26% or about $125 million of total expenditures. By 1985, energy science and technology (S&T) expenditures have been estimated to be $500 million or approximately 13% of all federal government S&T expenditures.

A large portion of federal energy R&D funding is under the general direction of the interdepartmental Panel on Energy R&D (PERD). PERD is chaired by the Department of Energy, Mines and Resources (EMR) and has 20 member departments and agencies. The Office of Energy R&D (OERD), in EMR, acts as a secretariat to the Panel and coordinates programs among 12 managing departments and agencies. Total PERD expenditures in 1985-86 were about $100 million, of which about $22 million was allocated to oil, gas and electricity R&D and an approximately equal amount was dedicated to heavy oil, oil sands and coal R&D. Within the allocation for oil, gas and electricity, most of the funds (about $19 million) are in support of frontier energy development.

Figure 4.1
Distribution of PERD Expenditures Forecast FY 1986-87



For fiscal year 1985-86 the federal government was expected to spend $100 million or approximately 2.7% of all federal S&T expenditures for oceans science and technology. While these expenditures are exclusive of fisheries and energy expenditures, they are of importance to frontier energy development. Several provincial and joint federal-provincial programs relating to fossil fuels and to enhanced oil recovery were described in Chapter 3.

Environmental research in the Canadian offshore is a significant area of expenditure, amounting to at least $48 million in 1984-85, funded by the federal government ($24 million), industry ($22 million) and universities ($2 million). These expenditures are primarily related to offshore oil and gas development.

Industry Expenditures

Of the total $2.5 billion of intramural R&D expeditures spent by all Canadian industries on R&D in 1983, $500 million or 20% is estimated to have been spent on energy R&D. Nearly 50% or $240 million of the energy R&D expenditures were spent on oil and gas R&D.

According to Statistics Canada, companies reported estimated expenditures of $251 million on oil and gas R&D in 1984, and projected expenditures will amount to $298 million in 1985 and $305 million in 1986. Many R&D costs are capital expenditures, such as the construction of pilot plants and *in situ* production. In 1984, the petroleum industry expenditures were offset by $20 million from the investment tax credit for R&D. About 50% of R&D expenditures were made in Alberta, 31% in Ontario, and 11% abroad. Approximately 1,800 persons were employed full-time in R&D in 1984 in the oil and gas industry.

Oil and gas companies reporting to the Petroleum Monitoring Agency spent $273 million on research and development activities in 1984. Of the total amount spent by these firms, $203 million or 74% was performed in-house. In-house expenditures were directed to refining ($63 million), exploration and production ($56 million), *in-situ* ($47 million), surface mining ($7 million) and "other" ($30 million). Of the $70 million in R&D performed under contract, approximately 40% was performed outside Canada. Trends in expenditures in recent years have been discussed in Chapter 1 of this report.

THE ORGANIZATION OF FRONTIER OIL AND GAS R&D

Numerous petroleum companies, associations, government agencies, consulting and engineering firms, research centres, and universities conduct R&D in support of frontier oil and gas development. Users of the research are wide-ranging and, aside from the oil and gas industry, include government departments responsible for shipping, fisheries, meteorology and defence.

Oil and Gas Industry

R&D in frontier regions, particularly research on environmental and operating conditions, tends to be widely shared and much research is undertaken on a cooperative, cost-shared basis. This approach has been adopted because of the large costs of operating in the frontiers and the relatively small number of active operators. Certain site-specific engineering research does remain confidential either to preserve a competitive advantage or to prevent a "free ride" by others. R&D is viewed as a means to an end and has very strong links with the economics of a project. Virtually all R&D sponsored by the petroleum industry is performed for the following closely related reasons:

- to conduct operations in hostile environments,
- to reduce operating and capital costs,
- to improve the safety and reliability of operations, and
- to meet government regulatory requirements.

The principal industry research organizations are:

- Arctic Petroleum Operators' Association (APOA), which has spent over $60 million on research during the past 14 years in the Canadian Arctic.

- Offshore Operators Division, Canadian Petroleum Association (OOD/CPA), which has spent some $20 million on research since the early 1970s through the Eastcoast Petroleum Operators' Association (EPOA). (EPOA no longer exists).

- Canadian Offshore Oil Spill Research Association (COOSRA) performing some $5 million in research over a five year period. COOSRA's activities have been phased-out, with the activities having been transferred largely to the Environmental Studies Revolving Funds.

Joint ventures are formed by industry groups in carrying out special projects and related research, such as:

- Polar Gas Project
- Arctic Pilot Project
- Arctic Gas Project
- Mackenzie Valley Pipe Line Research Limited
- Mackenzie Delta Gas Development System
- Beaufort-Delta Oil Project Limited
- Lancaster Sound Joint Venture
- Beaufort Sea Environmental Impact Assessment

As well, companies perform research in-house, particularly for site-specific requirements. Generally, operators conduct or manage most of the research required for their operations. In the Canadian offshore, operators having active drilling programs in 1984 (*) and examples of major interest holders are listed as following:

Beaufort Sea

*Dome Canada Limited
*Esso Canada Resources Limited
*Gulf Canada Resources Inc.
Home Oil Company Limited
Norcen Energy Resources Limited

Arctic Archipelago
*Panarctic Oils Ltd.
Dome Canada Limited
Consolidex Magnorth Oakwood Joint Venture
Petro-Canada Inc.

East Coast
*Mobil Oil Canada, Ltd.
*Petro-Canada Inc.
*Husky Oil Operations Limited
*Bow Valley Industries Ltd.
*Canterra Energy Ltd.
*Home Oil Company Limited
*Shell Canada Resources Limited
BP Exploration Canada Limited
Esso Canada Resources Limited
Canadian Offshore Resources Exploration Ltd.

As land holdings are most often farmed out, other partners share the costs of research.

Industry is also well organized in professional and technical societies and associations, including:

- Association of Consulting Engineers of Canada
- Association of Professional Engineers, Geologists and Geophysicists of Alberta (APEGGA)
- Canadian Geotechnical Society
- Canadian Society of Petroleum Geologists (CSPG)
- Canadian Society of Exploration Geophysicists (CSEG)
- Marine Technology Society
- Petroleum Society of the Canadian Institute of Mining and Metallurgy
- Society of Naval Architects and Marine Engineers (SNAME)

A significant proportion of oil and gas R&D and development of advanced technologies is contracted out. The principal procurement criteria of the industry consist of price, reliability, quality, and delivery. Many operators have adopted procurement policies stating that preference will be given to local and domestic suppliers if they are competitive on these criteria. The industry tends, however, to favour suppliers having a proven track record. In many cases, technologies used in other areas of the world, either in-house or from suppliers, have been adopted by the Canadian oil industry. Where a capability does not exist, oil and gas companies together with service and supply firms have developed new technologies. This has been particularly true in Arctic offshore operations, where Canadian firms have pioneered the development of a variety of new technologies. In recent years, the petroleum industry has initiated the Canada Market Opportunities Program (CMOP) to assist domestic suppliers in meeting the requirements of oil companies.

Service and Supply Community
The "traditional" service and supply community consists of firms whose principal services and products are used in conventional operations conducted on land in the Western provinces.

One large component of this community is in geophysical and geological services, which had sales amounting to more than $750 million in 1984. The geophysical industry, centred in Calgary, has world-class expertise but is extremely competitive, generally has poor financial returns, and prices for services match those of a decade ago. Overcapacity, the elimination of government incentives, and reduced exploration activities have resulted in a poor near-term outlook for geophysical companies. Geophysics and geology are technology-intensive activities, requiring highly-skilled personnel and state-of-the-art software and programming.

The Canadian market for oil field production equipment amounted to $489 million in 1983, down from previous years, such as in 1981 when this market amounted to $867 million. Domestic shipments in 1983 from over 400 firms amounted to $226 million with some 55% of the Canadian market being met by imports. Exports by Canadian firms represented only 2% of their total shipments.

Ocean Industry
The Canadian ocean industry plays a key role in providing services and equipment for the oil and gas industry. Over 250 companies comprise the ocean industries sector. Of these, a core group of about 50 companies depends on the oceans market for the majority of their revenues. By 1980, the core group of Canadian ocean industries had sales of $600 million, of which $30 million was export sales. Domestic sales increased from almost nil in the late 1960s to about $750 million in 1980. In the early 1980's the domestic market had been projected to increase to over $5 billion by 1990.

Several dozen ocean industries consulting firms offer expertise in R&D work in a variety of areas, such as:

- marine engineering
- naval architecture
- engineering
- environment and biology
- instrumentation
- management
- oceanography
- meteorology
- drilling services
- classification societies.

Canadian firms providing consulting services are located across Canada, in particular in Alberta, Ontario, Newfoundland and Nova Scotia. It has been estimated that these companies perform 50-90% of the design work for offshore petroleum operations.

In a study titled "*The Involvement of Consulting and Engineering Design Organizations in Technological Innovation for the Canadian Arctic Offshore Petroleum Industry* " (Tiffin, 1983) the roles of consulting engineering design organizations (CEDOs) were described as:

- the central point within a group of firms that drives and mediates information exchanges;
- a contract R&D lab as an independent source of innovative ideas;
- an agent involved in diffusion and in linking R&D to production;
- a central technology development group; that is, a centralized pool of technological expertise which is made available through contract;
- a gatekeeper of information; that is, a specialist in gathering information and creating information channels.

The study concluded that:

- Petroleum companies took the roles of carrefour, or organizer of projects and controller of major interactions among external groups.
- CEDOs did not have a unique control over technology, but shared in the responsibility for new ideas. An important aspect of this is the extremely close association of CEDOs with clients.
- The major role of the CEDO is the elaboration of the innovation and provision of specialized independent knowledge.

Another important finding was that a unique contribution of the CEDOs "*is in the role of developing and transferring technology as a central group*" for all Arctic petroleum operators. It was also noted that CEDOs are weak in execution roles, that is, in product development and manufacturing.

As well, the suggested reasons that companies such as oil and gas companies hire CEDOs stem from:

- the assistance available from CEDOs to firms coping with uncertainty by contracting specialists on a project basis;
- the need to meet fluctuating demand, e.g. as a "capacity buffer";
- efficiency reasons;

- the avoidance of bureaucracy, and access to entrepreneurial ideas and initiatives;

- the independence of the CEDOs in providing services in the client's best interests and adding confidence to design decisions.

Manufacturers and distributors of technology-intensive products include those in the areas of:

- communications equipment
- control systems
- diving equipment
- drilling and oilfield equipment
- electronics - e.g. marine communications and navigation
- instrumentation equipment
- metals, steels
- pollution control devices
- vessel propulsion systems
- safety equipment

Technology-intensive services include:

- diving and underwater services
- oil spill servicing
- drilling services
- surveys, logging, testing and positioning

Suppliers have organized trade associations including:

Canadian Advanced Technology Association (CATA)
Canadian Association of Oilwell Drilling Contractors (CAODC)
Canadian Oilfield Manufacturers Association
Canadian Shipbuilding and Ship Repairing Association (CSSRA)
Dominion Marine Association (DMA)
Energy Services Association (ESA)
Newfoundland Ocean Industries Association (NOIA)
Oceanic Canada
Offshore Trade Association of Nova Scotia (OTANS)

In 1979 the Sector Task Force on the Canadian Ocean Industry characterized the ocean industry as being small, fragmented and under-capitalized. While this report is somewhat dated, many of the findings of the Task Force are relevant today. Other characteristics of the industry identified by the Task Force were:

"- *low volume/high value custom-engineered products or services.*

- *employ mainly highly skilled people.*

- *mainly Canadian owned.*

- *have a high ratio of R&D costs/annual sales and long lead time from product inception to actual sales.*

- *have a strong potential for a several-fold increase in sales...*

- *must compete internationally with foreign firms much larger than themselves, yet have achieved significant export sales successes to date.*

- *many have world leading technology in a specific technical area."*

The potential contributions to the economy identified by the Task Force that could be made by this industry from 1980 to 1990 include:

- creation of 20,000-30,000 jobs in direct manufacturing and service industries and 150,000 indirect jobs,

- increased exports,

- help in ensuring that petroleum needs are met from Canadian sources using Canadian skills.

The Task Force stated that the future growth potential of the industry was excellent, but short-term rewards were not expected to be high. One of the recommendations of the Task Force was that the Canadian Ocean Technology Research Authority be established to co-fund technology developments in industry. The suggested funding level for the agency was $100 million over 5 years. Various other measures were recommended, including tax deductions for Canadian corporations engaged in high technology, exemption from federal sales taxes, negotation with other countries to establish reciprocal market access for specific products and goods, and waiver of duty payment for short-term importations.

Government R&D
The federal and provincial governments fund, perform, manage, or use the results of research and development activities through numerous departments and agencies and programs. About 300 federal government programs administered by 17 departments have a direct or first-order indirect bearing on the offshore oil and gas industry's scientific and technological activities. The primary reasons for performance of government R&D focus on:

- the need to have expertise in regulating industry and in providing independent expert opinion on proposals by industry;

- support for the provision of government services such as weather, sea and ice forecasting, and hydrographic charts;

- performance of R&D considered necessary but not being done by industry.

The federal government plays a major role in technology development through programs such as PERD and the Arctic Marine Transportation R&D Program. Commercialisation plans, contracting-out of projects and, in some cases, an entrepreneurial attitude by project managers, have contributed to a number of technological success stories. A small sample of technologies developed by suppliers through government R&D projects illustrates this:

- advances in electronic charts
- hydrographic remote sensing techniques
- positioning systems
- image analysis systems
- the DOLPHIN remote controlled survey launch
- airborne laser bathymetry systems
- emergency ascent diving bells
- offshore downhole temperature instrumentation package

It has been estimated that the sales of technologies in oil and gas (excluding oil sands and heavy oils) resulting from the PERD program has been about $30 million. Significant future growth has been projected.

Some of the major agencies or programs relevant to offshore oil and gas R&D are listed following.

FEDERAL
Energy, Mines and Resources (EMR)
Panel on Energy Research and Development (PERD)
Canada Centre for Mineral and Energy Technology (CANMET)
Canada Centre for Remote Sensing (CCRS)
Polar Continental Shelf Project (PCSP)
Atlantic Geoscience Centre (AGC)
Earth Physics Branch

Department of Indian and Northern Affairs (DINA)
- Northern Oil and Gas Action Program (NOGAP)
- Eastern Arctic Marine Environmental Studies (EAMES) Program

Canada Oil and Gas Lands Administration (COGLA)
- Environmental Studies Revolving Funds (ESRF)

National Research Council (NRC)
- Institute for Marine Dynamics (IMD)
- Division of Building Research (DBR)
- Hydraulics Laboratory

National Sciences and Engineering Research Council (NSERC)

Transport Canada
- Arctic Marine Transportation Research and Development (AMTRD)
- Canadian Coast Guard (CCG)
- Transportation Development Centre (TDC)

Environment Canada
- Ice Forecasting Central
- Arctic Marine Oilspill Program (AMOP)
- Offshore Labrador Biological Studies (OLABS)
- Baffin Island Oil Spill Study (BIOS)
- Atmospheric Environment Service (AES)
- Environmental Protection Service (EPS)
- Federal Environmental Assessment Review Office (FEARO)

Department of Fisheries and Oceans (DFO)
- Canadian Hydrographic Service (CHS)
- Institute of Ocean Sciences (IOS)
- Marine Sciences and Information Directorate

Bedford Institute of Oceanography (BIO)
- Atlantic Oceanography Laboratory
- Marine Ecology Laboratories
- Atlantic Geoscience Centre (EMR)
- Atlantic Region, Canadian Hydrographic Service

Department of Industrial Regional Expansion (DRIE)
- Ocean Industry Development Office (OIDO)

Department of Communications

Department of National Defence

PROVINCIAL

Province of Newfoundland
- Newfoundland and Labrador Petroleum Directorate

Newfoundland Oceans Research and Development Corporation (NORDCO)

Province of Nova Scotia
Nova Scotia Research Foundation Corporation (NSRFC)

Government of the Northwest Territories
Science Institute of the Northwest Territories (SINT)

Universities and Research Centres
Universities have over the past decade increased their involvement in oil and gas-related R&D. Those having close links with technology development in the frontier include Memorial University of Newfoundland and the University of Alberta. The Arctic Institute of North America, located on the University of Calgary campus, has worked with the oil industry, particularly through the provision of the Arctic Science and Technology Information System (ASTIS).

Research Centres supported jointly by universities, governments and industry consist of:

- Centre for Frontier Engineering Research (C-FER)
- Centre for Cold Oceans Engineering Research (C-CORE).

Other centres having specialized capabilities include:
- Technical University of Nova Scotia
- Laval University
- McMaster University
- University of British Columbia
- Dalhousie University
- University of Toronto
- York University

Numerous universities are involved in northern studies and are organized through the Association for Canadian Universities for Northern Studies (ACUNS).

Universities have the primary responsibility for the delivery of sufficient numbers of qualified scientists and engineers in marine science and technology. There is a long lead-time in developing qualified scientists. It is apparent that in the short term, sufficient graduates will be available in certain disciplines (e.g. marine biology), while there may be shortages in other fields (e.g. marine geophysics). In the longer term, the very narrow age range of marine scientists within government and universities may present problems in the 1990s. At present, difficulties exist in the recruitment of younger scientists, given the few openings available.

While universities generally have limited activities in applied oil and gas-related R&D, considerable academic expertise exists in marine sciences. However, they lack cohesion and concentration in their activities, which have been described as being "spread too thin".

Universities have also found it difficult to attract expert engineers to university positions, partly due to low salary levels compared to the oil and gas industry.

Data Suppliers

Canadian data suppliers (libraries, on-line computer searches and data sales) include:

- Arctic Institute of North America (AINA), Arctic Science and Technology Information System (ASTIS)
- Arctic Petroleum Operators' Association
- Centre for Cold Ocean Resources Engineering (C-CORE)
- Pallister Resource Management Ltd.
- Canada Institute for Scientific and Technical Information (CISTI)

Technology Transfer
The work of the numerous organizations in industry, government and universities over the past 15 years has resulted in Canada having a distinct advantage and leading edge in technologies required for operating in cold, remote areas typical of Canada's frontiers. This complex array of companies and agencies conducting R&D has led to a variety of coordinating mechanisms to reduce duplication of effort and secure the benefits of technology transfer. As a result, technologies tend to diffuse rapidly where there is effective use of technology transfer mechanisms, such as:

- joint participation in projects - R&D and joint ventures
- close physical proximity of performers, e.g. jointly-funded research centres located on campus
- cooperative programs, equipment and facilities (e.g. oil spill co-ops)
- publication of reports and papers
- interdepartmental committees
- workshops, seminars and conferences
- industry advisory committees for government programs
- joint government-industry management boards and program committees
- consulting companies. Such firms tend to work very closely with their clients and have been identified as key agents in technology transfer. In many cases, the oil industry contracts out work that requires specialized expertise or facilities.
- government procurement
- by adoption of technologies from suppliers and manufacturers
- exchanges of personnel

The principal obstacles to technology development, transfer and commercialisation are inter-related and may be grouped in the following manner.

A. FINANCIAL OBSTACLES
Unstable, short-term funding resulting in short-term projects. Secure and sustained funding has been increasingly difficult to obtain in government, industry and university programs, owing to the existing cost-reduction environment. As well, offshore operations are now only in the exploration phase, and sufficient reserves have not yet been discovered which could justify a very large, stable base of

expenditures, like that associated with developments in the North Sea. As a result, suppliers are cautious in expanding capacity until the larger, more stable markets are evident. In some cases, prototypes of advanced hardware have been developed but will not be commercialised until a firm market exists.

Lack of available funding from private sources, either through venture capital funds or through banks. Principal reasons given are the high risks associated with commercialisation of technologies and, for knowledge-intensive activities, the lack of required collateral, which is often intangible - e.g. ideas, concepts, and expertise. On the other hand, products and services that have immediate application in meeting real needs do receive private funding, owing to their comparatively lower risk.

Limitations of government funding programs. Government programs have emphasized support for capital costs and have generally assumed that companies have a cash flow to support R&D. Programs to cover operating costs and seed funding for start-up operations are seen to be less effective than capital assistance programs. The 1984 review of government programs by the Task Force on Government Policies and Programs (the "Wright report") resulted in numerous recommendations. Certain of these recommendations are now being addressed by the federal government. It is not widely known, however, that the government is doing so. This lack of information has left many in industry wondering if there is any value to such reviews. A formal federal response and an indication of follow-up actions would be desirable.

B. STAFFING

Difficulties in maintaining staff and teams of experts. This is particularly a problem in the event of cyclical downturns, transfers to other companies, and in view of the high cost of training.

Too few persons. Concern has been expressed in government that there are too few person-years (p-y's) devoted to managing contracts and government facilities effectively.

C. RESEARCH MANAGEMENT

Difficulties in the establishment of research priorities; especially for research that is not responding to a demand or to real needs. This subject, as related to government R&D programs, has also been discussed at length in the Wright report. A major difference in opinion exists between government and industry over what is "necessary" and what is "nice to know". In essence this reflects disagreements over research priorities and levels of activities. Here, a distinction is required as to the R&D needs of specific companies, of the industry as a whole, and the R&D needs of governments. Another problem recognized by industry is the attempt by government to justify R&D on the basis that "industry requires this information" when this is in fact not the case.

A continuing debate centres on *the balance between basic and applied* *research and the roles of government and industry in R&D.* Some industry personnel, particularly at senior management levels, are critical of government R&D. It appears that this criticism is based largely on ideological rather than technical grounds. Good working relations are evident among government and industry scientific personnel. Government R&D programs tend to address more basic and longer-term research, while industry's programs are oriented to more short-term and site-specific work. Government considers itself to be a client of R&D as industry is, but each may have different needs. One related concern is the criteria for measuring the success of R&D. It has been pointed out that progress too often is defined by the amount of resources (funds and persons) devoted to projects. This may or may not have a direct bearing on the significance or usefulness of the results obtained.

Insufficient thresholds in efforts to obtain desired technological advances. Comparisons have been made between the limited R&D facilities in Canada and those in the U.S. where very large commercial R&D firms can provide support and staff for intensive efforts. From a national perspective, Canada's R&D is fragmented and thinly spread. Attempts to resolve this difficulty have led to "centres of excellence" where a concentration of expertise exists. As well, specialization has occurred resulting in identification of niches where Canada can either compete effectively in the world market or open new markets with innovative products.

Inertia of research plans. In rapidly changing or uncertain projects, such as some frontier projects, a problem may cease to exist while the solutions are still being sought. As well, the problem definition may evolve but the R&D may not keep pace with these changes.

D. LIAISON

Insufficient use of consultation, communication and feedback mechanisms, e.g. scientists and managers working in isolation, insufficient dissemination of information. The R&D information infrastructure, such as communications and notice of technical advances, are of crucial importance in technology diffusion. Poor information flow is a major concern in federal programs, yet it can be easily remedied.

Confidentiality or lack of access to literature, e.g. "grey literature". The problem of the "free ride" exists in making research available. Companies can, however, purchase an interest in studies, provided of course that they know about the studies.

Lack of common standards in data and lack of unified bodies of knowledge.

E. MARKETS

Limited markets. Certain technologies are "one-of", involving the development of expensive prototypes. Some technologies are custom made for site-specific requirements. Other technologies can, however, find wider application in other industries or in the international market.

As well, if "core" technologies are developed, these can be customized for site-specific application.

Lack of assets and credibility. Small innovative firms may have innovative ideas and products but lack cash and credibility. Joint ventures of small and large established firms have proven to be the most effective means of handling this problem.

Uncertainties in the development of technology (i.e. serendipity). There are certain incompatibilities between scientific and industrial processes of technology development. For instance, a technological breakthrough cannot always be predicted or planned. As a general rule, successful commercialisation of technologies has been achieved by careful problem definition followed by careful selection of alternative solutions.

International competition in fabrication and manufacturing. Canadian costs for large projects such as platforms and vessels greatly exceed costs in Japan, Korea and the Scandinavian countries. The marine transportation industry in Canada produces large but few units (i.e. ships) annually. Innovations can be copied in a short time, providing little incentive for R&D.

Market Potential for Advanced Technologies
The Sub-Committee on High Technology of the Major Projects Task Force stated that:

> *"The Canadian Energy and Transportation Programs reviewed by the Major Projects Task Force represent over the next two decades by far the most significant opportunity for achieving an intensification of technological activity by linking the resource sector to the manufacturing sector and the research community."*

While noting that advanced technology expenditures are infinitesimal compared with the overall costs of the project, the Sub-Committee stated that "*the paradox is that even expenditures at levels of 1.5 percent of project costs imply a very significant impetus to national technological activity*", given the large total project costs.

Although it has been widely assumed that the era of mega-projects has passed, a number of large projects were still being planned in 1985. Recent figures indicate that over 50 major oil and gas projects valued at about $54 billion could be underway in the oil and gas industry before 1995. "Major projects" are defined as those projects having a minimum investment value of $100 million in 1984 constant dollars which are presently underway, or could be underway before 1995.

Table 4.1
Possible Major Oil and Gas Projects 1985-1995

Type of Project	# of Projects	Value ($billions)
Oil and Gas Development/Production	18	$23.332
Oil and Gas Exploration	12	$ 7.304
Refined Petroleum	1	$ .700
Pipelines	13	$22.408
Totals	54	$53.744

Frontier Oil and Gas Exploration and Development	$16-24 billion
Northern and East Coast Natural Gas Pipelines	$18 billion
Oil sands, Heavy Oils, Enhanced Oil Recovery	$11 billion
Total	$45-53 billion

The Sub-Committee on High Technology of the Major Projects Task Force provided estimates of "technology opportunities" from major projects. Based on estimates of percentage expenditures with recent figures on major oil and gas projects listed above, over $800 million could be spent on electronics technologies, primarily instrumentation, data processing, and control equipment by 1995.

The Sub-Committee also estimated that between 5% and 25% of the capital costs of offshore hydrocarbon production and transportation systems will be for technology-intensive equipment and systems. If this very rough rule-of-thumb is applied to three projects either planned or expected to take place, the expenditures shown in Table 4.2 would be applicable.

Table 4.2
Major Possible Offshore Oil and Gas Projects 1985-1995

Hibernia	$ 5.5 billion
Venture	$ 3.3 billion
Beaufort Sea	$ 3.7 billion (single island development with tanker transportation)
Total	$12.5 billion
5%	$625 million on advanced technologies
25%	$3.125 billion on advanced technologies

It was also assumed by the Task Force that 25% of high technology content is in labour for design and engineering. In the illustrative example above, a minimum of some 3100 high technology person-years could result fom these three projects.

Expenditures on oil and gas activities by operators on the Canada Lands have been increasing over the past four years as shown on the following table.

Table 4.3
Frontier Oil and Gas Expenditures and PIPs

Year	Expenditures	PIPs*
1981	$1.079	$ .469
1982	$1.424	$ .974
1983	$1.927	$ 1.252
1984	$2.185	$ 1.393

*Petroleum Incentives Program.

In 1984, with the exception of $72 million associated with development of Norman Wells reserves, all expenditures were related to exploration. Approximately $2 billion, or over 90% of these expenditures, was spent on the offshore and all were for exploration activities. During exploration, activities are conducted primarily on a seasonal basis, although in recent years the drilling season has been expanded. Where possible, year-round operations from permanent facilities will be used for production. As exploration proceeds to production and transportation, there will be larger expenditures by industry.

The regional breakdown of frontier expenditures in 1984 was as follows:

Table 4.4
Frontier Oil and Gas Expenditures by Region
($ billions)

North of 60	$ 1.053	(Including Hudson Bay)
Nova Scotia	$ .618	
Newfoundland	$ .514	
Total Canada Lands	$ 2.185	

ORGANIZATION OF R&D FOR OIL SANDS AND HEAVY OILS

AOSTRA

R&D on oil sands and heavy oils is carried out by a variety of performers, including government agencies, companies, universities and engineering firms, but one organization dominates the field: the Alberta Oil Sands Technology and Research Authority (AOSTRA).

Since 1976, AOSTRA has committed approximately $300 million to oil sands and heavy oils research. It receives its funding primarily under the Alberta Heritage Savings Trust Fund, with an added small amount of its revenue (about 4% in 1984) coming from technology sales. AOSTRA has identified the following areas in which industry requires technical support:

- recovery of bitumen from deeply buried parts of the Athabasca deposit
- upgrading of bitumen and heavy oil upgrading
- water treatment
- residue and coke conversion
- equipment testing
- laboratory support
- data storage and retrieval.

AOSTRA supports industry in all of these areas through joint research projects and pilot projects with companies, through support for university research, and through funding research in government organizations such as the Alberta Research Council and the Saskatchewan Research Council.

In 1984, AOSTRA's $37.8 million of expenditures were distributed as follows:

Table 4.5
Distribution of AOSTRA Expenditures, 1984

	%
Institutional research	27
In situ oil sands	22
Enhanced oil recovery	15
Mining and extraction	9
Underground access	9
Carbonates	8
Heavy oil	3
Bitumen upgrading	3
Technology handling	2
Training activities	1
International activities	1
Total	100

The expertise developed by AOSTRA has placed Alberta as the oil sands/heavy oil technology centre of the world. AOSTRA markets Canadian technology, equipment, experience and technicians around the world, and now has formal agreements for technology exchange and research with 18 countries. These agreements can include commitments for joint funding of research, such as that with the U.S. on experimentation with additives for *in situ* steam injection.

In addition to its research and technology transfer roles, AOSTRA played a major part in sustaining pilot projects through the economic recession of the early 1980s, thus allowing industry to maintain and advance its technological development.

Provincial Government R&D
Other major provincial government participants in oil sands and heavy oil research include the Alberta Research Council (ARC) and the Saskatchewan Research Council (SRC).

The ARC program focusses on *in situ* bitumen extraction from oil sands reserves that are 50 to 800 metres underground, and on understanding the geological features of these deposits. In 1984, ARC spent about $8 million on oil sands research out of a total budget of $37.4 million.

The Petroleum Division of SRC has recently assumed ownership and operation of the former R&D Division of Saskoil, including the Heavy Oil Laboratory. It offers R&D services to industry in enhanced oil recovery, production, upgrading, analysis, and technical information. SRC is especially interested in developing techniques to recover, treat, and upgrade Saskatchewan heavy oils.

CANMET
At the federal level, the Canada Centre for Mineral and Energy Technology (CANMET) has the major responsibility for research on heavy oils and oil sands. CANMET's budget for this work is about $17 million in 1986/87. In its Long-Term Plan, 1985 to 1990, CANMET identified the following seven major R&D areas in heavy oils and oil sands:

- treatment of bitumen/oil emulsions and effluent waters,
- recovery of bitumen and heavy oil,
- upgrading technologies for bitumen, heavy oils and residuals,
- catalytic process development for hydrocarbon conversion and distillate upgrading,
- characterization of liquid fuels and development of separation processes,
- development of bitumen/heavy oil and coal coprocessing technology,
- gasification and pyrolysis (converting hydrocarbon materials such as coal, oil shales, wood, oil sands coke and other residuals to synthetic gas).

The bulk of CANMET funding for this R&D comes from the interdepartmental Panel on Energy R&D (PERD). Not all of the work is undertaken in CANMET's own laboratories; in some projects, a major part of the work is contracted out to the private sector and universities. Under PERD, Environment Canada is responsible for about $1.5 million in 1986 for environmental R&D related to oil sands and heavy oils.

Universities
Universities are also active in heavy oils and oil sands research, especially the University of Alberta, University of Calgary and University of Saskatchewan. However, a large number of projects are funded at universities in other provinces as well, primarily through AOSTRA.

Industry R&D
The larger companies involved in the development of oil sands and heavy oil deposits, such as Syncrude, Suncor, Esso, Husky and Petro-Canada, carry out their own R&D programs.

An even greater number of companies participate in experimental pilot projects on *in situ* and enhanced oil recovery, jointly, individually, or with AOSTRA. In addition, large engineering firms carry out R&D, mainly on upgrading facilities and processes; for example, Partec-Lavalin with Petro-Canada in the CANMET upgrader project.

Technology Transfer in Oil Sands and Heavy Oils
The relatively small community of companies involved in these developments, the large number of joint R&D projects, and the existence of AOSTRA all contribute to a successful system of technology transfer.

AOSTRA plays a key role in marketing technologies developed through its participation in R&D projects. There are two main routes offered by AOSTRA to those interested in gaining access to these technologies: pre-completion and post-completion of projects. At the pre-completion stage, any interested third party may become a "consultative participant" by paying a small percentage of the cost of the project, usually 6% of gross or 10% of net. This gives the third party commercial use rights to the technology but no active part in the management of the project nor any interest in assets or any rights to revenues from production or licensing. At the post-completion stage of the project, access may be obtained through contractual arrangements, with the purchase price based on the fair market value of the technology. Licence fees are established by AOSTRA and the industrial participant in the original project.

For AOSTRA-supported R&D projects in universities, the University/Industry Access Program permits third parties to purchase the use rights to inventions and technical information from any university/AOSTRA project by paying 5% of the total cost of the project.

AOSTRA's successes in promoting the transfer of technology have contributed to Canada's pre-eminent position as the world centre for oil sands and heavy oils expertise.

INTERNATIONAL PERSPECTIVES

Canada is second among all International Energy Agency (IEA) countries in government expenditures on energy RD&D (excluding nuclear) per unit of gross domestic product. Canada also is very active in IEA's collaborative RD&D program.

Energy policy objectives of IEA member companies are similar, with the primary objective being the avoidance of dependence on imported oil. Energy RD&D policies of these countries help achieve this and other objectives, such as:

- improving energy use and conservation
- generating scientific expertise
- maintaining the ability to adopt foreign technologies
- fostering international cooperative projects
- providing employment
- encouraging industrial innovation.

According to the IEA, Canada is notable among the IEA countries in instituting a procedure whereby proposals for government energy RD&D are accompanied by a commercialisation plan. This plan includes the identification of firms that will carry out the commercialisation of successful R&D results.

The petroleum industry has a very strong and competitive international supplier community for both onshore and offshore equipment. Suppliers active in the North Sea, Gulf of Mexico and Pacific Rim provide most of the competition for advanced technologies and vessels in the Canadian offshore oil and gas market. The United States, Norway, the United Kingdom, Sweden, Finland, Japan, and Korea have all developed and/or manufactured advanced technologies for operating in deep waters and harsh conditions, such as are required in operating in the Canadian offshore. The strengths of these companies rest in their proven capabilities, aggressive marketing, and financial strength. These strengths provide significant competitive challenges to Canadian firms. Other difficulties facing Canadian suppliers, best exemplified in the marine transportation sector, are foreign government subsidies, declining markets, a comparatively strong Canadian dollar, tariffs, and higher Canadian labour costs. It has frequently been pointed out that intense efforts are required to exploit international markets.

International cooperation is necessary and desirable in obtaining technologies at low costs. One approach being taken to access foreign technologies and expertise is provision of joint venture agreements between foreign and Canadian firms. This may involve the phasing-out of foreign companies in activities once technologies have been acquired. Technology transfer licensing agreements with other countries have proven to be an effective means of upgrading Canadian expertise.

Canada's trade promotional programs include the Promotional Projects Program (PPP) and the Program for Export Market Development (PEMD). Through PPP, trade fairs, missions and visits are organized and implemented. PEMD funds are available to Canadian industry to cover costs in developing export business. As well, the Export Development Corporation provides insurance against non-payment, issues guarantees, and assists in financing arrangements. The Cost Recoverable Technical Assistance Program makes Canadian government expertise available to governments involved in development programs and to Canadian firms participating in such programs.

Canadian industry has developed capabilities that have world-wide acceptance, technological competence and commercial viability. Examples of such technologies are:

- hydrographic and seismic survey systems (underwater deep-towed systems and aerial hydrography)
- oceanographic survey systems
- sub-sea vehicles (manned, unmanned, tethered and autonomous technology, and research capability in cold water and ice conditions)
- sub-sea well completion systems
- turbines and parts
- geophysical equipment
- underwater acoustic equipment.

The following market opportunities for advanced technologies and services supplied by Canada's ocean industries and impediments to capturing these markets have been identified in recent years. In all cases, market forecasts were made before the oil price declines in 1986.

Norway
The market for oil and gas equipment and services in Norway for North Sea operations is expected to be $35 billion (1982-1992). Recently, Norway has permitted oil and gas operations to proceed further north, where operating conditions are more severe. As such, many of the technologies Canada has developed would be applicable to the northern North Sea.

The principal impediments to entering this market by Canadian firms are the "Norwegianization policy", entrenched foreign competition, lack of knowledge of Canadian capabilities and Norway's industrial cooperation policy.

The Norwegianization policy consists of raising the level of national ownership and Norwegian operator responsibility in order to increase the use of Norwegian goods and services and to encourage industrial research and development cooperation. The government has set the objective that Norwegian firms shall have a gross share of deliveries of goods and services of 70% and a net share of 50%.

Research and development technology agreements that have been formalized have consisted of "50% agreements" (a requirement for 50% of R&D conducted in Norway), participation agreements (cooperative research programs with Norwegian R&D centres) and Goodwill Agreements (a declaration from companies stating their intention to carry out as much R&D in Norway as possible).

Norway has developed bi-lateral agreements on industrial cooperation, including R&D, with Sweden, West Germany and France.

United Kingdom
Goods and services for offshore oil and gas equipment and services in the U.K. amounted to $6 billion in 1983. About 70% is met from U.K. suppliers. Between 1984 and 1995 this market is estimated to be $100 billion.

The market is open to foreign suppliers on a commercial rather than a preferential basis. The role of the Offshore Supplies Office is to ensure that British industries have a "full and fair opportunity to compete in supplying goods and services" to this market.

While a number of Canadian firms have entered this market, activities are dominated by other countries, such as the U.K., U.S., Norway, France, Holland, and Italy.

Japan
The ocean industry market in Japan amounted to $2.1 billion in 1979. While Japan has a strong domestic ocean industry, a large market for foreign suppliers remains. Japan lags behind Canada in certain ocean technologies. Opportunities exist in:

- ocean research and related technologies such as communications equipment

- oil and gas drilling and production equipment

- consulting engineering services

- pollution control systems

- diving systems and services

Concern has been expressed by several persons contacted during this study over the transfer of technology from Canada to Japan and other countries, particularly in arctic marine technologies.

USA - Alaska

Opportunities for Canadian firms exist in:

- production systems
- ice management techniques
- ice-capable support vessels
- cold weather operational experience
- enhanced oil recovery systems
- drilling systems
- subsea pipelines
- near-shore transportation systems
- offshore storage and transportation systems

USA - Offshore California

- subsea production concepts
- enhanced oil recovery techniques

USSR

Exploration and possible production of northern offshore hydrocarbons in areas such as the Barents, Kara, and Bering Seas could provide opportunities for Canadian ocean industries. It is unlikely that existing USSR technology adapted from temperate regions could be used to operate safely in northern ice-covered waters. In recent years, the Soviets have used Finnish drillships in such areas.

The USSR has embarked upon an ambitious enhanced oil recovery program, which also could be assisted by Canadian firms.

5. TECHNOLOGICAL REQUIREMENTS

A. OFFSHORE OIL AND GAS

OPERATING CONDITIONS AND ACTIVITIES

Technologies for the exploration, production and transportation of frontier oil and gas differ significantly from those used in temperate regions. Depending on the specific region these offshore operating conditions include the presence of ice and permafrost, high sea states, water depths, unstable seabeds, darkness, and cold weather. Operations are expensive and often have to be conducted during short seasons. Logistics in remote regions are also more difficult. To ensure safe operations and minimal down-time, equipment and systems must be rugged and fail-safe. While there have been some demonstration projects, no commercial oil or gas production presently exists from the Canadian offshore. The distinctive operating conditions of the various frontier regions tend to require site-specific technologies, although certain technologies are transferable among regions.

Beaufort Sea

The Beaufort Sea has a 150 to 200 km wide continental shelf with water depths up to 200 metres. Exploration activity has been conducted principally in water depths of less than 50 metres. The seafloor is soft and the sub-surface contains permafrost. The open water season extends from July to October of each year. During the remaining eight months of the year, the Beaufort Sea is covered by ice, either seasonal ice, permanent pack ice or ice ridges. Some thick ice islands and ice ridges ground and scour the seafloor.

In shallow water depths of up to 25 metres, exploration drilling has been performed from artificial islands constructed from granular materials that have been either dredged from the seafloor or transported over ice from land. Recent developments have included the use of caisson-retained islands and a semi-submersible drilling caisson that can operate on a year-round basis. These concepts are expected to be applied to permanent production bases.

In deeper waters, both Dome Petroleum Ltd. and Gulf Canada Ltd. have used floating drilling units (drillships and a conical drilling unit) for exploration drilling. With the assistance of ice-strengthened vessels the new generation of mobile drilling units has extended the drilling season to December of each year. Floating units will not be feasible for year-round production in the Beaufort Sea owing to ice forces.

Substantial oil and gas reservoirs underlying the Beaufort Sea have been identified. Industry is presently delineating these fields and has conducted a significant amount of planning for the eventual production and transportation of oil and gas from the region. Production concepts focus on the use of retained artificial island technologies and could extend to discoveries in water depths of up to 60 metres.

Provision would be made to allow tankers to dock and load oil from the islands in deeper waters of the Beaufort Sea. In shallow waters oil would be transported to shore by subsea pipeline, and then by pipeline to connect with existing pipeline networks in southern Canada.

The companies proposing development have completed an environmental impact statement that has been reviewed by the public and by the Beaufort Sea Environmental Assessment Review Panel. The Panel has stated that the production and transportation concepts could proceed provided that they meet certain conditions and are carried out in a small-scale and phased-in manner. The Panel has recommended that a number of research initiatives be undertaken in support of the project.

Arctic Archipelago

The waters of the Arctic Archipelago are almost completely covered by ice for most of the year. Offshore drilling has been conducted from reinforced natural ice platforms during winter months when the ice is stable. Operations are suspended before the summer when ice breaks up and moves. Offshore reservoirs are located up to 35 km from shore and in water depths that can exceed 500 metres.

A demonstration production system has been successfully installed and operated in shallow water close to shore. Subsea production and pipeline systems are planned for this region, if sufficient petroleum reserves are established. Once on shore, petroleum would be transported by tanker to southern markets. During 1985, Panarctic Oils Ltd. commissioned the delivery of the first tanker of oil from the Bent Horn field on Cameron Island on a demonstration basis.

Eastern Arctic

The waters of the Eastern Arctic, consisting of Lancaster Sound, Baffin Bay, and Davis Strait, have an ice cover in winter and icebergs during the summer. These ice conditions, strong ocean currents, and deep waters require the use of dynamically-positioned drillships or semi-submersibles for exploration drilling. In certain areas, seafloors are often covered with hard rock, resulting in difficult and expensive wellhead installation problems. In many areas, particularly the Lancaster Sound, protection of the natural environment is a major concern.

Given the very difficult operating conditions, exploration drilling has proceeded slowly and at present no drilling is taking place. Production from this area is speculative, but is expected to be by subsea methods.

East Coast

Exploration drilling has been active off the coasts of Nova Scotia and Newfoundland for decades and significant quantities of oil and natural gas have been discovered. The geology of the East Coast is complex, and reserves have been smaller than expected. As a result, smaller and more flexible production systems than are used elsewhere may be required.

Icebergs and high sea states are two critical operating constraints in the offshore Labrador and Grand Banks areas. Seafloor scour by icebergs poses a major problem in the production phase. Conditions are far less extreme on the Scotian Shelf.

In recent years, operators have been conducting exploration and delineation drilling focussed on the Grand Banks and Scotian Shelf and Slope. Plans have been developed to produce and transport oil from Hibernia and natural gas from Venture. Except for the presence of ice, operating conditions at Hibernia are similar to those of the North Sea. Operating conditions off Nova Scotia are less demanding, such that production from Venture will use proven technologies. In other areas off the East Coast, operating conditions are more difficult, involving deeper waters, and further north, iceberg hazards are greater.

Oil and gas companies operating in Canada's frontiers require new technologies that are not only innovative but also adaptable and capable of withstanding the harsh offshore operating conditions. These new and emerging technologies and their applications are described in the following sections.

REQUIRED TECHNOLOGIES

The exploration, production, and transportation of frontier energy require technologies that enable operations to be conducted in various environmental conditions. Depending on location, these operating conditions include:

- the presence of ice
- high sea states
- varying water depths
- unstable seafloor conditions
- the presence of permafrost
- cold climates
- darkness

To ensure safe operations and minimal down-time, equipment and systems must be rugged and fail-safe. Development of these oil and gas resources provides a significant opportunity for the growth ocean industries having technology-intensive services and products.

Technologies required are in the areas of:

- Information Acquisition and Management
- Optimization of Ice-Classed Vessels
- Offshore Production Structures
- Ice Engineering and Ice Management Techniques
- Advanced Materials
- Subsea Systems
- Environmental Protection
- Natural Gas Management
- Safety Equipment and Systems

INFORMATION TECHNOLOGIES

Data Acquisition and Management

The primary requirements for information technologies are the provision of accurate, reliable and timely data for analysis, prediction and decision-making associated with the planning and operation of oil and gas projects. Technologies are required in the acquisition, transmission, reception, analysis, and integration of data.

A variety of data must be acquired for the design and operation of offshore facilities, whether during exploration drilling, production or transportation. Hydrography and seabed conditions, and sensing of ice masses, atmospheric and sea-state conditions are major areas in which data are required frequently. Sensors that have high resolution and all-weather capabilities and that can be used remotely have the greatest applications. For most existing systems, improvements can be made in better resolution and temporal coverage. Alternative energy sources having low power demands are required for these remote sensors.

Within the next decade oceans-related information systems are expected to advance rapidly; existing information systems are undergoing a virtual "revolution" that provides significant opportunities for development of technologies. Advances in information technologies include:

- new generations of sensors and instrumentation, e.g. acoustic devices and more sophisticated remote sensing techniques
- increased archival and access advances
- increased computing speeds
- microwave transmission of data
- data handling systems
- expert and artificial intelligence systems

These technologies will be applied in operational ocean services, climatology and long-term weather and oceanographic forecasts, research needs, decision-making, and improved data bases.

A combination of techniques is required to collect data on atmospheric conditions. For instance, the Canadian Atlantic Storms Project (CASP) was planned to investigate in detail features of winter storms off the Maritimes. Technologies include:

- McIDAS (Man Computer Interactive Data Access System) to superimpose various images and maps onto a single screen,

- new radar technologies that measure ocean currents at large distances,

- WOTANS (Wind Observation through Ambient Noise), an underwater listening device to measure wind speeds,

- sophisticated laser-based instruments that measure wind, temperature, pressure, and precipitation,

- use of a several buoys and instruments offshore to measure ocean currents, water temperatures, wave heights.

Improvements are possible to unmanned current profile measurement and recording, particularly through better performance and lower power requirements.

While synthetic aperture radar (SAR) and side-looking airborne radar (SLAR) have been widely used in recent years as airborne remote ice sensing systems, new developments are expected to improve the capabilities of these systems. Developments include improved real-time down-linking to users, systems that do not require specialist expertise to run, and low cost, high resolution image displays. SAR is considered an excellent system for the detection of sea ice, but moving icebergs can smear on the imagery. Systems thus require refinement or development of new techniques to handle these data. Intera Technologies of Calgary is one example of a firm developing and providing these services. As well, the Canada Centre for Remote Sensing (CCRS) has been active in the development of various sensing devices used in ice detection.

Depending on the specific system, existing satellite sensors have limitations in their infrequent coverage, spatial resolution, and requirements for clear weather. With the eventual deployment of RADARSAT, detection of ice conditions is expected to improve considerably.

Canada is a leader in the area of radar detection of ice. A major R&D effort is being directed to improving ship-borne radar for ice detection by increasing the range (e.g. over-the-horizon detection) and resolution of radar. R&D has also been directed to the identification of smaller ice features that are not always detected by existing radar systems, particularly in high sea-states. Tactical ice monitoring work has included the use of buoys arranged in an array that detects ice masses by radar, and transmits high-resolution data to the ship.

Additional work is proceeding on the characterization of icebergs. Canada has substantial expertise in sea ice studies, including data collection, analysis, modelling, and understanding the interactions of ice with vessels and structures. Improvements can be made, however, in the capability to determine ice thickness and ice properties remotely, which could result in better characterization of ice masses and their potential effects on operations.

Advanced techniques for geotechnical sampling and remote detection of seafloor characteristics are finding increasing application. An example is a focussed acoustic beam that can differentiate materials on the seafloor. Modifications to geophysical systems are also possible for the identification and delineation of ground ice and permafrost.

Technologies associated with geophysical systems include lower cost data acquisition methods for areas of ice cover and offshore permafrost. As well, advanced techniques are being developed in software and processing of data. One major federal program, the Frontier Geoscience Program, has been undertaken to establish a data base on frontier and offshore geophysical information.

Rapid and less costly techniques for the measurement and compilation of hydrographic data are becoming increasingly important because of the projected increase in vessel traffic associated with oil and gas development and transportation. Accurate data will be crucial to the transportation of oil and natural gas by tanker from the Arctic.

Technologies are needed that will efficiently chart bottom topography, provide rapid and accurate water depths (particularly through ice, broken ice and snow), determine low water definition, and permit transitting vessels to make soundings through ice. Examples of emerging technologies include: efficient electronic sweep systems, XSV system enhancement, use of radio wave methods and transducer fields, techniques for sounding through ship hulls, launch/ship hydrographic auto pilots, and side-tow array systems.

Better methods, such as through using active shortwave techniques, are required to map the areal extent and depths of ice scours.

As many facilities such as manifolds and pipelines will be located on the seafloor, there will be a demand for cost-effective technologies to install and remotely inspect these facilities.

In the event of an oil spill, rapid detection and movement monitoring of the spill are required. Both CCRS and the Canadian Offshore Oil Spill Research Association (COOSRA) have investigated the use of various systems to perform these functions, including laser profilemeters, and low light television combined with computers and real-time display hardware.

A major area of R&D is in monitoring structures and vessels under severe conditions, such as ice loading or wind and wave loading during storms. Monitoring instruments have been developed and the data are used to assess the integrity of structures and vessels and to detect potential failures. The information obtained can lead to cost reductions by reduced inspection needs and improving design information. The monitoring of more extreme forces over long periods will require more durable instrumentation; such as the use of vibration-based techniques, acoustic emission hardware, ultrasonics, and fibre optics.

Navigators presently receive a wealth of data from numerous information systems, including ice and weather reports, notices, high-frequency radio systems, and satellite data. These data have varying accuracy and relevance. Problems persist with the timely non-manual processing of data. Electronic charts have been used in navigational systems, but further improvements are possible through electronic data analysis, filtering, storage, and display. Applications exist for precise, integrated navigàtional systems using high speed and high resolution colour graphics at varying scales. Technical advances are required in the areas of surface and sub-surface navigation systems, LORAN coverage, the Global Positioning System (GPS), and active and passive acoustic devices as positioning systems.

Reliable communications systems are needed that can perform in all types of weather, year-round, night or day. They must also be free of electromagnetic disturbances, which is a common problem in northern operations.

Fibre optics may have a variety of applications in communications, information and control functions, hydro-acoustic systems, down-hole logging, and seismic applications.

Data collected in support of offshore operations are provided on computer data bases and marine information systems. Different users require different types of data. For instance, consultants use long historical data series for design work, whereas operating companies need real-time information. Canada has advanced nautical and engineering data bases that are widely used. While these data bases provide valuable information, there is no standardized format for data collected. These data bases are expensive to maintain. Integration of various data bases, or increased compatabilities among data bases, would lead to a more comprehensive and efficient marine information system.

Models for Design and Decision-Making

An enormous amount of data exists that must be analyzed and applied by specialists. Foreseeable advances are in the areas of software development, expert systems and computer modelling, such as:

- improved short and long-term ice state forecasting abilities, particularly for ice conditions, e.g. break-up, freeze-up;

- improved methods to measure and interpret ocean surface parameters such as ocean currents, wave height and wind velocity;

- improved ice kinematics modelling. Predictions of the movement of icebergs are presently limited by the complexity and difficulty of acquisition of relevant data.

- development of computerized structural load models, such as that being pursued by Det norske Veritas that provides a means to evaluate the interaction of structures or vessels with ice and other loads, based on utilization of site-specific information;

- integration of real-time data. Satellite data have been down-linked to the *MV Arctic* in near real-time display. Future developments will include systems that integrate airborne data with other remotely-sensed data. An example of such a system is the Multi-Task Ice Data Analysis System (MIDAS) being developed by Transport Canada.

- quality assurance and quality control of offshore structures and vessels using computer modelling;

- simulators, trainers, and electronic computer displays, particularly for emergency or crisis management;

- interpretation of complex geology. Significant advances are being made in expert systems for the application of processing and interpretation techniques to high resolution seismic reflection data.

- models for forecasting oil spill distribution. More advanced models would be used for deployment of resources in the event of an oil spill.

- data for the design of structures and production sites. An example is Bow Valley's BEAU-DATA'SS program to assist in structure selection, determination of gravel quantities, preparation of budget estimates, and development of logistics plans.

- enhanced cartographic methods using computer-based storage, access and displays.

MARINE VESSELS AND PLATFORMS

A wide variety of specialized vessels and platforms will be required to supply, support, and perform drilling and production operations. The principal requirements for the development of vessels and offshore structures are in optimization to handle a wider range of ice and sea-state loads, and optimization in design and materials to reduce costs. Refinement of techniques will result in minimizing over-engineering and thus reducing the costs of vessels and structures. For example, more accurate data obtained in the laboratory and in the field indicate that ice forces are less than previously estimated. As a result, new designs for structures and vessels require less costly solutions. Designs of offshore production structures and icebreakers are progressing from "brute force" approaches to designs that are more sophisticated yet, in many cases, less costly.

Technological developments are proceeding in the areas of:

- ice-classed transitting vessels
- drilling and production structures
- materials
- ice engineering and ice management

Ice-Classed Transitting Vessels

Surface operating vessels that will be required in support of offshore oil and natural gas exploration and production include:

- seismic vessels
- arctic dredges
- supply and standby vessels
- shuttle tankers
- icebreaking cargo tankers
- air-cushioned vehicles or hovercraft

These vessels will either be developed or modified to incorporate results from ice engineering and hydrodynamics, resulting in more efficient and safe operations. Components of transitting vessels that are being developed further include: hulls, structural components, load lines, propulsors, rudders, steering gear, shafting, and propellors.

Icebreaking or ice-strengthened oil and LNG tankers are fundamentally different from tankers used in ice-free waters in terms of their design, shape, propulsion and in their construction. Although few of the world's icebreakers can travel through the more severe ice conditions, considerable advances have been made in the past decade. Hull strengths, performance of various hull forms and propulsion requirements are now better understood. Novel features such as icebreaking hull forms (such as spoon-shaped bows), air bubbler systems, controllable pitch propellors and use of fixed propellor nozzles have been incorporated into more recent designs. Dome's proposed arctic tanker has been designed to have double hull construction, multiple and independent propulsion systems and rudders, and would use inert gas systems in the cargo hold, while having the capability to travel year-round through the Northwest Passage. The *Manhattan*, the Canmar *Kigoriak* and the *MV Arctic* are instances of floating laboratories where the ship's performance and ice forces are monitored and the results are utilized in new icebreaker designs.

Concepts of tanker loading and mooring facilities in ice-covered waters, such as the Beaufort Sea and High Arctic, similarly require further work, particularly if operations are conducted during extended seasons.

While air-cushioned vehicles (ACVs) are now in use, they will have new applications suitable for offshore oil and gas operations. These applications include: use in shallow water transport; as standby vessels in severe weather, particularly where high speeds are required; as oil spill dispersant spray vehicles; as research vessels; and in transporting large and heavy cargoes. R&D into the reduction of high energy usage by ACVs could enhance their cost-effectiveness.

Drilling and Production Structures

Experience to date in the Canadian offshore has primarily been with exploratory drilling units used on a seasonal or short-term basis. New generation units have extended the drilling season, and artificial islands have been used year-round. The primary requirements for production structures in the Beaufort Sea, Arctic Archipelago, and East Coast are:

- design and construction of permanent year-round structures that either withstand ice forces or avoid ice by moving off location or through subsea systems;

- optimization to handle a wider range of ice loads, particularly extreme events;

- optimization in design and materials; and

- development of new methods for operations in deeper waters.

In certain cases, structures and technologies developed for exploration and delineation drilling have applicability to production operations, depending upon location.

To date, numerous concepts have been proposed for production from the Canadian offshore. In many instances, these designs were formulated when oil prices were higher, and where large oil fields were assumed. With falling oil prices and the discovery of oil fields that are both smaller and more complex than anticipated, future concepts will have to be substantially more cost-effective and will require new technologies.

For instance, one area requiring further R&D is in the area of grillage structures standards. Design rules have been based on ship design experience, and have led to extremely conservative designs. A review of the design basis of grillage systems, tests on structural sub-assemblages and incorporation of results into offshore structure design standards; could yield improved economies of structures.

Due to the significant differences in operating conditions among regions, and even within regions, production structures frequently must be custom-designed and manufactured.

Off the East Coast, exploration units consist of semi-submersibles, drillships, and jack-ups. Where icebergs are present along the East Coast from Lancaster Sound to the Grand Banks, present practice in exploration drilling is to use conventional platforms, divert icebergs, and discontinue operations or move off location when large icebergs cannot be avoided. In shallower waters, the very large icebergs ground on the sea bottom, and collisions are avoided.

Thus, depending on water depth, a permanent, year-round structure must either be able to withstand extreme loads of very large icebergs or move off location. Production structures off Nova Scotia, where conditions are not severe and ice is not a problem, would consist of platform complexes in 20 to 25 metres of water and would utilize proven technology. In deeper waters and in areas off Newfoundland where conditions are more severe, either bottom-founded systems, floating production systems, or hybrids (fixed base with floatable upper portions) are expected to be used. At Hibernia, Mobil has proposed the use of a gravity base structure (GBS), a concrete bottom-founded platform. Floating production systems are attractive in development of smaller offshore fields. These systems may be either ship-shaped or of semi-submersible design.

Floating and hybrid production systems will require more R&D and engineering work, particularly in the areas of mooring in high sea-states using dynamic positioning, rapid-disconnect techniques, control of drift once off location, and repositioning on location, all while remaining cost-effective. Other areas requiring further technical development include evacuation, riser dynamics, the use of ice cutters, and finding solutions to problems of dropping mooring lines on subsea equipment. Loading oil onto tankers poses problems in turret mooring for large fluid flows to tankers, and in the design of high pressure multi-pass lines (water, gas, produced fluids, and controls) that are able to swivel. As well, articulated loading platforms operating under severe conditions will require further development.

A totally subsea production system has not yet gained industry's acceptance, so there would have to be reliance on underwater production systems combined with surface platforms. While subsea production has been conducted on a demonstration basis, this has been from a shallow-water site near to shore. To develop large reservoirs located in deeper waters will require advancements in subsea technologies.

Ice conditions and water depth are the primary determinants of the types of production structures that would be used in the Beaufort Sea. Ice conditions include landfast ice, a shear zone, and intrusions of multi-year ice. Exploration and delineation drilling have been performed in shallow waters less than 25 metres deep by using artificial and gravel islands, and caisson-retained islands. Caisson-retained islands such as Gulf's *Molikpaq* and Esso's CRI have been demonstrated as an effective means of drilling less expensive wells by reducing the fill requirements of islands. The experience gained from such structures will be used in the design of future production islands.

Advances are required in the improved understanding of the interaction of soils and structures and then applying this knowledge. Investigations and solutions are necessary in the area of berm scour and stability under extreme environmental loading conditions in artificial island designs. Other structures such as the Dome/Canmar SSDC mat concept do not use a soil berm to support the drilling structure. Additional R&D would be valuable in determining the properties of silty soils on a site-specific basis through computer analysis models in relation to structural settlement and strain. One relevant development would be the prediction of horizontal sliding resistances involving ice-loading on bottom founded structures using computer finite element, soil/structure interaction models and field experiments.

Using dynamic positioning, drillships are able to stay on location within a few percentages of water depth from the well site. Further advances are possible in exploration and production systems that tolerate greater motion of the surface floating unit. While floating production systems have been considered principally for use off the East Coast, they might also be used on a seasonal basis in the Beaufort Sea. As moving ice may disrupt operations, one approach that is being considered is the use of high-pressure flexible pipe risers. A major problem in using such a system is the handling of riser length to allow the surface facility to drift from the well.

In areas of multi-year ice, permanent production platforms require massive gravity structures owing to the large ice loads. In waters up to 60 metres deep, artificial islands are favoured by operators. Alternative concepts have been suggested, and include steel and concrete conical and monopod gravity structures. Movable gravity platforms have potential use in the Beaufort Sea, although their very large and massive size results in high costs.

Given the expense of all operating platforms, whether islands or gravity based systems, it is possible that each field would have a small number of gravity structures used in conjunction with underwater production facilities. Alternatively, a completely subsea, remotely-controlled production system may be used in the future.

Ice Engineering and Ice Management

The presence of ice is one of the most critical conditions of operating in the North and off the East Coast. With rates for drilling and support operations at times exceeding $200,000 per day and considering the very large investments in offshore vessels, industry has strong incentives to utilize methods that reduce down-time and improve the safety of operations.

Significant work has been conducted since the early 1970s in the field of ice engineering. Future work will be directed to refining and consolidating data, testing of various vessel and structure configurations under various ice conditions, and developing more effective methods of handling ice. Improved knowledge of ice properties leads to optimal designs of structures. Work is being conducted on areas such as sea ice growth, influence of ice microstructure on structural loads, fracture toughness, ice loading models, and iceberg temperatures. One R&D emphasis is on ice dynamics, which includes investigations of wave-induced motions, the influence of pack ice on iceberg motion, and iceberg-seabed interactions.

Ice-structure interactions receive a considerable emphasis in Canadian R&D. Areas of interest include ice loading, behaviour of ice with various structures, protection of structures, artificial island geometries, effects of structures on ice regimes, ice conditions along shipping routes, and mathematical modelling and small-scale tests using ice tanks. Canada has a leading expertise in ice engineering.

Ice management techniques have been developed more recently along with new active and passive icebreaking and clearing systems. Depending on location, methods employed include ice bubblers, ice growth suppressors, and protective ice fields. Work is proceeding on the fragmentation of icebergs; that is, how to break large icebergs into smaller masses, or how to weaken icebergs to promote their breaking. Improvements are being sought in iceberg towing, particularly in the attachment of lines to the icebergs, and in improved iceberg diversion techniques. As well, methods of dealing with vessel and structure icing are being addressed through R&D projects.

Improved knowledge of ice scouring of the seabed is required in order that the location and depth of scours can determined more accurately. A statistical and probabilistic approach to estimate safe burial depths of submarine pipelines is being pursued.

Materials

Materials used in the offshore must have a variety of desired properties, including high strength, durability, low maintenance requirements, and low weight. If exposed, they must be resistant to corrosion, and they must perform well under low-temperature conditions and large temperature variations. Advances are needed in the understanding of the properties, design and fabrication aspects of these materials. Steels, concretes, steel-concrete hybrids, ice, and granular materials are the primary materials used for construction of offshore structures.

Concretes
Lightweight and durable concretes using additives such as silica fume, superplasticizers, and lightweight aggregates are expected to have increasing use. Such materials have been used in systems such as the Global Marine Concrete Island Drilling System (CIDS) in the Alaskan Beaufort Sea.

Steels
Advances are being made in the optimization of low-temperature steels having a variety of desired properties. Drilling rig components operate in low temperature environments when exposed outside, and high temperatures during drilling. Steels are required for drilling and production structures and down-hole tubular products.

Tubulars must be of high strength and low temperature ductility for northern operations. As exploration wells are required to be drilled deeper, higher loads are placed on drill strings, casings and production tubings. Deeper wells frequently involve higher downhole temperatures and more severe corrodants. Bending loads must be accommodated, particularly as some drilling programs propose highly deviated production wells. Steel companies are improving products through continuous casting, desulphurization and improved quality control measures.

Advances in offshore drilling and production structures will be required. Specifically, systems being researched include concrete and steel-concrete composites, ice resisting walls and cast steel nodes for triangulated structures and steel shear walls. Composite ice-resisting walls comprised of steel outer plates, a core of concrete, and shear-resisting components interconnecting the two materials, show promise but require further testing and analysis.

One area of technical development is in fabrication of steel components under arctic conditions. Drilling rig components operating in low temperature environments are often of bolted design. Further testing of fabrication processes with the aim of weight reduction, in these conditions would be useful. Increased efficiencies are also possible in the welding of steels in low temperatures, particularly in minimizing or eliminating pre- and post-heating during fabrication.

The properties of steel in large measure determine how effectively steel components can be joined by robots at greater water depths. Such remote processes include the use of lasers and electron beams, and represent an area where further development is required.

Fabricators could improve production schedules by utilizing to full advantage state-of-the-art CAD/CAM technology and mechanized fabrication methods.

Other R&D areas relevant to offshore structures and vessels in the area of long-term corrosion resistance in arctic seawater include:

- welding procedures
- development of short term testing of long term behaviour assessment
- further developments in cathodic protection systems
- development of special welding consumables
- performance of various types of steels

Corrosion-protective coatings and additives, such as urethane, polyethylene, and ceramics, in fabrication and repair will be increasingly necessary. While additives and protective coatings exist, they need to be improved and customized for Arctic conditions.

Ice
Ice reinforced with synthetic materials and artificially thickened has been used for exploration drilling platforms in the High Arctic and has been used in providing a protective ice berm in the Alaskan Arctic. These technologies have been demonstrated successfully and may find application in other Arctic regions where ice is stable.

Sealants
Methods, such as flexible connectors, for joining equipment that operate in rugged environments require further development.

SUBSEA TECHNOLOGIES

Oil and Gas Production

Operators have favoured production systems having accessible surface facilities. As a result, most of the emphasis on production systems has been on massive structures capable of withstanding large ice loads and/or high sea-state conditions. Certain components of production and transportation systems will, however, be located on the seafloor. The advantages of subsea completion and production lie in their removal from surface conditions, thus eliminating the reason for large structures. Subsea technologies have particular application in deeper waters and in areas having severe ice conditions. In such areas it is possible that remotely controlled underwater production facilities will be used in the future.

In the Arctic Archipelago, Panarctic successfully demonstrated a subsea completion/production project. Subsea production systems have also been considered for use in the Beaufort Sea and off the East Coast.

The principal requirements associated with subsea technologies are:

- the ability to complete, produce and transport hydrocarbons safely from the wellhead to surface facilities, vessels or to shore,

- the ability to monitor, maintain, and control subsea equipment.

Depending on location, the relevant operating constraints on the seafloor are:

- ice scouring,

- hard seafloors,

- unstable seabeds, owing to offshore permafrost, sediment transport, unconsolidated sediments, and seismic activity.

Projects in geotechnical R&D are pursuing solutions to these constraints in order that the stability and integrity of subsea pipelines, artificial islands, and bottom-founded structures can be assured. Relevant technologies needed include reliable field equipment and instrumentation that will monitor operating conditions and facilities' performance. Advanced techniques, such as acoustic sensing of sediment properties, are being demonstrated. Improvements to geotechnical data banks, and in the methods by which R&D results are made known and available would be valuable.

A number of drilling problems have been encountered in offshore operations. In the Beaufort Sea these have included ice scouring, requiring protection of the subsea wellhead; washouts in the surface hole; control of hydrates and pressure reversals; and preventing permafrost from melting during drilling. As well, shallow over-pressured water sands beneath permafrost are encountered frequently. Solutions to the problems of well control have been implemented, requiring state-of-the-art logging units, pressure detection instrumentation, and advanced well control techniques. "measurement-while-drilling" providing real-time data on formation characteristics have been well-received by operators and are used frequently. Further advances are possible in intelligent systems that could monitor drilling parameters and automatically initiate control action, yet remain subject to manual over-ride.

Hardware operating on the seafloor must be rugged, reliable, be made of suitable materials, and have minimum maintenance requirements. Advances will be required in:

- protection from ice scour of well equipment, flow lines, and pipelines on the seafloor,

- dredging in deeper waters more economically,

- trenching and tunnelling through rock in areas of ice scour,

- installing subsea production equipment,

- inspecting, maintaining and repairing subsea systems. For subsea inspection, maintenance and repair, high endurance manned and unmanned submersibles are required in certain circumstances. In some applications, this may be achieved manually, although requirements exist for improved diving safety equipment and infrastructure such as hyperbaric chambers and for improved diver training. In deeper waters and harsh conditions, servicing could be performed remotely by robots. Command, control, and communications systems for under-ice operations are required.

- more simplified subsea techniques for subsea production, particularly for smaller fields. At present, down-hole equipment and certain related subsea systems have intricate machinery and "swiss watch" complexity that create excessive down-time. "Elegant" facilities and "exotic" field techniques may have potential for developing small production systems. Demonstration projects for such concepts are, however, expensive.

- advances in remotely operated vehicles (ROVs). Canada is presently a world supplier of ROVs and is a leader in this field.

- fibre optics in sensors for undersea (ROVs),

- new propulsion systems for ROVs, e.g. jet power,

- improved underwater welding processes,

- development of equipment controls, such as control umbilicals, electrical controls, controls for valve operations, and continuous monitoring of operations. These may be achieved by methods such as ultrasonics, and fibre optic filaments (which have the advantage of better signal transfer without electrical interference).

- undersea communications, e.g. digital telemetry,

- use of non-acoustic telemetry systems for well control,

- operation and control of multi-phase flow lines under a variety of conditions such as pressure drops and waxy and heavy oils,

- use of heat tracers in lines carrying heavy or waxy oils,

- inspection of multi-phase pipelines, including the launch and operation of smart "pigs" that would enter such lines to locate areas of corrosion and material defects,

- more reliable large diameter (20"-30") high pressure valves,

- power sources for subsea operations,

- improved marine risers,

- subsea oil storage facilities.

Submarine Transport
Concepts have been developed for submarine oil tankers to transport oil under the ice. One concept is that of a submarine tanker powered by a non-nuclear fuel cell using methanol and liquid oxygen. Technologies required include methods for crew escape and rescue, for transfer of cargoes while under the sea, and for submerged docking. Investigations have been undertaken into a submarine tanker pulling a shuttle with cargo. The use of submarines has not received much interest from the oil industry and may be considered a possible long-term development.

PIPELINES THROUGH FROZEN GROUND
The major pipeline projects that have been proposed are the Polar Gas Project (designed to bring natural gas south from the Mackenzie Delta and the High Arctic), the Alaska Highway-Dempster Lateral (from Prudhoe Bay and the Mackenzie Delta) and an oil pipeline from the Beaufort Sea. Methods for installing and operating oil pipelines through or on permafrost have been successfully demonstrated. Projects include the Trans-Alaskan Pipeline System (TAPS) and Interprovincial Pipelines' line from Norman Wells to Alberta. If buried, large oil pipelines have major problems with the disruption of permafrost. As such, the TAPS line was raised on stilts in thermally sensitive areas.

Future projects will rely heavily on the experience gained from the construction and operation of these pipeline projects. There are, however, important differences.

The amount of reserves from the Beaufort Sea, the timing of their development, and the environmental and social impacts will necessitate construction of small or medium diameter lines from this area. In contrast to the line from Norman Wells, pipelines from the Beaufort Sea will encounter more severe permafrost conditions. R&D is required to identify in greater detail the location and types of subsea permafrost. This may involve new hardware and software. Methods of protecting permafrost from large subsea oil lines have to be tested if such lines are used. Such lines would be contained within a buried trench for protection from ice scour, and thawing of permafrost could be avoided through insulation of the line, cooling the oil or chilling the line. Alternatively, smaller lines could be used which are not expected to disturb the thermal regime. In sensitive permafrost soils the overland line would use cryanchors filled with a refrigerant that chills the ground as required. Areas of R&D relevant to onshore oil lines include designs to ensure slope stability, and insulation methods to avoid thermal disruption of permafrost. For instance, thick layers of wood chips have been used for insulation in the southern regions of permafrost. As wood chips are progressively unavailable further north, other materials such as plastics may be used. The behavior of such materials through freeze-thaw cycles is, however, not well understood.

Thermally-insulated pipelines have been developed to avoid the formation of waxy-viscous substances and hydrates during transportation which are difficult to transport in pipelines. Solutions to avoid thermal losses have included electric tracing, parallel heating fluid lines, injections of chemicals and recirculation. Other systems, such as that patented by Snamprogetti, involve the use of insulating materials such as polyurethane surrounding the pipeline.

Frost heave and permafrost thaw associated with large natural gas pipelines continues to be an area requiring further R&D. The Dempster Lateral and the Alaska Highway mainline will be buried in frozen and unfrozen soils. The line will be chilled through frozen ground to prevent permafrost thaw. Backfilling and other insulating measures would be used to prevent frost heaving in unfrozen ground. Other design considerations include the effects on the line from stream flooding and changing stream channels and possible disruptions of ground water supplies.

If gas lines are laid from the Arctic Archipelago as proposed by Polar Gas, advanced techniques may also be required in the areas of pipelaying, repair, and maintenance in ice-covered waters.

ENVIRONMENTAL PROTECTION

Oil Spill Countermeasures

Offshore oil spill countermeasures in Canada's frontiers have required new solutions to problems of operating in cold waters, ice-covered waters and high sea-states. Advanced design and delivery of systems for the detection, surveillance, containment, recovery, and disposal of oil are required.

In spill detection, work has proceeded using airborne synthetic aperture radar (SAR) and laser profilemeters. Remote sensing techniques have been supplemented by oil spill trajectory modelling. For instance, ultraviolet and low light TV systems are being combined with a computer system that analyzes data indicating the relative thickness of oil. Further work may lead to measurements of the absolute thickness of oil. Oil spill trajectory models have been developed but require further development and testing.

Several methods for containment and disposal of oil spills, such as igniters, air-portable incinerators, fireproof booms and skimmers have been developed. Improvements are needed in oil absorbents. *In-situ* burning shows promise in the Arctic, although limitations exist in ice-covered waters. Laser ignitors may find application for burning oil spills. Techniques are needed that will separate oil from ice rubble. Dispersants work poorly in cold water, especially with heavy, waxy, cold oils, requiring a good deal of mixing of the dispersant with the oiled waters. Further work is needed in the verification of laboratory or small-scale tests of the use of chemicals in real, offshore conditions. Research on sub-sea containment equipment has been pursued but an inexpensive and effective solution has not yet been found. New solutions are required that are effective in the higher sea states on the East Coast and in handling oil in broken ice.

In the event of an oil spill, large amounts of environmental and logistical information needs to be assembled and provided in a timely manner. One approach that is being taken by some oil companies is the development of a microcomputer data base that supports decision-making in support of a spill response. Data are displayed on a computer monitor and include biological features, locations of dwellings, and sites important to logistics such as wharves, airports and helipads. With this information a coordinated and rapid response to an emergency is facilitated.

Environmental Monitoring and Mitigation

Canada has achieved a leading role in environmental impact assessment and methods of mitigating impacts. Environmental research is necessary not only in protecting the environment, but is also essential in support of safe operations. The emphasis on environmental-related research is on improved knowledge and understanding; that is, most of the developments are science-based and result in technical information rather than hardware products. Software and expertise of scientists are, however, marketable products and services.

Areas requiring advanced technologies or further R&D include:

- data gathering systems for wildlife location, behaviour patterns, migratory routes; and meteorological and oceanographic variables,
- use of low cost portable video tape recording equipment for coastline surveys for oil spill contingency applications,
- monitoring and sensing of pollutants,
- long-term effects of waste drilling fluids,
- waste and wastewater treatment technologies,
- methods of mitigating the effects of hydrocarbons and trace metals on the environment,
- reducing impacts from noise generation,
- site restoration.

A number of recommendations relevant to environmental research have been identified by the Beaufort Sea Environmental Assessment Panel. Of interest to science and technology issues is one recommendation that the Government of Canada make a commitment to a fifteen-year program of accelerated Arctic research. A federal policy providing a national focus for short and long-term research was also proposed. As well, other needs identified were by the Panel were: a commitment to encourage research in the North by northerners; increased support for basic research; a program designed to strengthen university centres for Arctic research and a special tax write-off for industry-sponsored research in the Arctic. The Panel forwarded a number of other recommendations concerning matters such as oil spills, R&D on tankers, research on ice-breaking and the need for improving government's technical capability in evaluating proposals by industry.

NATURAL GAS MANAGEMENT

In remote offshore locations such as the Grand Banks, the Beaufort Sea, and the Arctic Archipelago, it will be uneconomic to bring natural gas to shore during the early years of oil production. The available options are to flare the gas, which is wasteful; to reinject it for enhanced oil recovery; reinject it for disposal; or to process it to liquefied natural gas (LNG) or methanol and bring the product to market. The latter method faces difficulties in economics and certain associated technological problems that could be addressed through R&D.

SAFETY EQUIPMENT AND SYSTEMS

Since the loss of the *Ocean Ranger* in 1982 a substantial amount of effort has focussed on R&D related to safety equipment and systems. Safe operations depend upon the adequacy of technologies previously identified in this report, in particular: data acquisition and management (knowing the hazards); models for design and decision-making (preparing for and responding to hazards), the design of drilling and production structures (preventing hazards) and ice engineering and ice management (managing hazards).

Technology can play an important role in improving the safety of operations but safety depends also on a variety of other key factors, including management, training and the regulatory regime. The most comprehensive and authoritative sources on safety relevant to the Canadian offshore are the two reports of the Royal Commission on the Ocean Ranger Disaster, dated August 1984 and June 1985. Material in the following section is largely based on these reports, with the emphasis being on the role of technology in safety. A synoptic review of these reports has been taken; readers are encouraged to consult the Commission's reports for a more complete assessment.

Emphasis is given in the Commission's reports to the need for accelerated R&D in specific areas, including R&D to: improve the measurement and accuracy of forecasts of weather and oceanographic phenomena; improve ice surveillance and management techniques; better forecast and monitor the physics and climatology of icing; and to produce a safe primary evacuation system through a joint major engineering development project.

R&D required to improve the safety of operations identified by the National Research Council for the Commission consisted of suggestions for R&D in the areas of:

- Improved Safety Criteria
  - Behaviour of Offshore Structures
  - Modelling Improvements
  - Analysis of *Ocean Ranger* Model Test Data
- Improved Environmental Monitoring
- Icing of Offshore Structures
- Iceberg Research
- Simulation of Control Systems
- Evacuation Procedures
- Properties of Materials
- Offshore Communications
- Remotely Controlled Submersibles

While safety systems are changing rapidly, some of the technical problem areas and technologies being developed in response to the needs of safety equipment and systems are described following.

Safety design
Computer-based risk analysis and probability models are being developed to assist in the design of offshore structures to withstand a variety of loads. Production structures, particularly if enclosed, may have buildups of gases resulting in explosion and fire hazards. In such cases, structural fire protection components require further development. Technologies to address this hazard include improved gas buildup detection systems and monitoring equipment, and improved reliability of automatic control systems. As well, further R&D is required in the area of cold environment firefighting problems.

Evacuation
Evacuation of up to several hundred people from a drilling rig or production platform poses significant problems. The second report by the Royal Commission on the Ocean Ranger Marine Disaster stated a serious concern with the paradox of:

> "*ocean-going drilling rigs, designed and instrumented at the "leading edge" of technology*" contrasted to the "*anachronistic system of lifeboats and life rafts to protect the workers.*"

Emphasizing this point, and noting the "*astonishing lack of technological progress in evacuation systems for offshore rigs over the years*", the report states that:

> "*there is, at present, no proven system for the evacuation of offshore drilling rigs that can assure a reasonable chance of survival to those who are obliged to use it during severe storms and other environmental hazards. More specifically, there is no existing evacuation system which is adequate for the environmental conditions frequently encountered in the drilling areas off the eastern coast of Canada.*"

The general approach described by the Commission to escape and survival is:

- normally, the safest haven offshore is the rig itself;

- in the event of abnormal circumstances such as ice incursions, storms, structural damages, fire, blowout, the escape of toxic gases, evacuation may be needed;

- the first line of defence has been to reduce the need for evacuation through rig design and support operations;

- the second line of defence has "*been to determine when evacuation may be required in sufficient time to choose the safest method*", by helicopter, or if not possible, dry transfer to a standby vessel, or use of lifeboat and life raft, and if that is not possible, directly to the sea.

One of the recommendations by the Commission (#22, in its first report) was that "*Canadian authorities consider the development of an evacuation system that will 'provide and adequate and safe means of escape in foreseeable emergency and storm conditions to be a matter of the utmost priority and that they encourage through every means at their disposal the earliest development and use of a safe system*". In response to this recommendation, the Canadian Coast Guard and Memorial University of Newfoundland have conducted a survey of existing and potential evacuation systems; the Department of Energy, Mines and Resources and Transport Canada have encouraged the research and testing of new evacuation systems; and the Coast Guard has taken the role of federal coordinator to lead evacuation systems R&D.

Many advances are being made in the rapidly evolving area of evacuation systems. Totally enclosed lifeboats made of low temperature grade steels provide one possible solution. One approach being taken is for an "arctic escape system", an all weather amphibious vehicle and launching system, capable of being deployed in a variety of conditions and able to traverse a number of ice conditions.

For underwater work, a submersible compression chamber designed for controlled emergency ascent is presently being tested in the PERD program. Work has been accelerated in the development of certain lifesaving equipment, such as: inflatable escape slides, radar transponder wristwatches, extractor membranes to obtain oxygen from seawater, survivor detection, and free-falling lifeboats. Immersion suits that are easy to work in are being designed and developed. Safety rescue boats for severe weather conditions do require further development work.

The Commission recognized that advances are being made in escape and survival systems, yet emphasized in its second report (June 1985) that:

> "*Recent developments have essentially been improvements in the lifeboat rather than new ideas. Perhaps what is now needed are breakthroughs and radically new concepts... There is a pressing need for systems that are simple, reliable and above all, safe to move people off a rig in distress in Canada's storm- and ice-ridden eastern waters; there is then a need for rescue systems that will find them, succour them and bring them safely home.*"

Search and Rescue

Standby vessels having fast rescue craft and crane-operated rescue baskets are primary resources used during search and rescue operations. Limitations have been identified in their effectiveness under storm conditions.

Advances have been made in the development of the emergency multiple person rescue apparatus (EMPRA) which can transport survivors by helicopters. Helicopters are severely limited by range and weather conditions. Air-cushioned vessels have potential applications, but their reliability has been questioned and requires further work.

In recent years, search and rescue capabilities have been improved through the application of existing technologies to aircraft and vessels. Upgrading of search and rescue resources include use of advanced communications systems, automatic flight-control systems, use of radar and positioning equipment. Emergency position indicating radio beacons (EPIRBs), emergency locator transmitters (ELTs) and personal location beacons (PLBs) play important roles in location of survivors during emergencies. Fixed frequency transmitters with lower power demands would find application in search and rescue operations.

The Commission noted that advances are required in in improved communications methods for health care for offshore operations. Telemedicine, the transmission of medical data, has already begun to improve the consultative process between rig medic and onshore physician. Basic biomedical research is still required in certain areas such as hypothermia and other conditions experienced during marine emergencies.

B. HEAVY OILS AND OIL SANDS

Technologies for exploiting oil sands have in the past been very different from those used for conventional oil or heavy oil. The original oil sands mining developments at Suncor and Syncrude required a long development time because of unique problems of overburden removal, operation of large scale equipment in a wide range of temperatures and conditions, and the abrasiveness of the oil sands ore. Now, however, these technologies are available and demonstrated, and with the well known and extensive resource base, technical, reserve, and cost risks would be low for new developments in surface-mined oil sands. The major technological opportunities in oil sands mining operations exist in the extraction and processing of bitumen from the oil sands ore.

The greatest challenge in new oil sands technology lies in the development of *in situ* techniques for bitumen recovery from deeper deposits. Such projects are on a smaller scale than the huge surface mines and now seem to be of greater interest to industry than the mining mega-projects. In mid-1985 two *in situ* operations came on stream at Wolf Lake (BP/Petro-Canada) and at Cold Lake (Esso Resources), both located in Alberta. By the end of the year, both operations were performing near capacity.

The key to heavy oil development lies in enhanced oil recovery (EOR) techniques. While such techniques are used for conventional oil, and as primary recovery techniques for *in situ* bitumen extraction from oil sands, the nature of heavy oils and their reservoirs require further development and demonstration of EOR technology.

For both bitumen and heavy oils, upgrading will open new markets in Canada by transforming these heavy crude oils to lighter grade crude that can be processed in domestic refineries. At the same time, increased upgrading capacity will alleviate the shortage of diluent, expected to become a problem in the 1990's. Diluent, usually pentanes plus, is required to reduce the viscosity of heavy crudes to allow them to be shipped by pipeline. Heavy oil upgrading projects would eliminate a large amount of heavy crude requiring diluent and would produce diluent for use with other heavy crudes.

The following sections describe the various stages of oil sands and heavy oils development and identify opportunities for new technologies.

Oil Sands Mining
Mineable deposits of oil sands, that is, those under less than 75 metres of overburden, cover about 324,000 hectares or 7% of the total area of the Athabasca Oil Sands. These deposits are composed mainly of sand, clay, water, and bitumen, with variations in composition occurring not only between deposits but within them as well. The basic procedures of oil sands development are: removal of overburden, mining of the bituminous sand, and extraction of the bitumen from the sand using a hot water process. Both major oil sands projects, Suncor and Syncrude,

operate in this manner.

When a deposit has been identified as being suitable for exploitation, trees are cleared and the remaining muskeg ground cover, two to seven metres thick, must be drained using ditches. The drainage process takes up to two years. Between the muskeg and the oil sand is another layer of overburden composed of sand, gravel, clay, and silt. This layer is also removed and used to construct tailings dams, dykes, and eventually to fill in mined-out areas.

Overburden removal is a significant cost in surface-mined oil sands projects: the waste-to-ore ratio is a key indicator for screening potential mine sites. As the mining operation moves into areas of increasing waste-to-ore ratios, the company faces steadily increasing overburden removal costs. One possibility for reducing these costs is hydraulic transport of overburden material. Bench scale testing at Syncrude has been promising, but full scale field testing is required to ensure that an environmentally acceptable deposit without high reclamation costs will result.

In order for the huge Suncor and Syncrude operations to be economic, enormous amounts of oil sand must be mined, moved, and processed continuously. At Suncor, mining is done by self-propelled bucketwheel excavators, half a city-block long. Each excavator carries a wheel with 10 buckets at the end of a boom. The wheel revolves so that each bucket removes a chunk from the mine wall and then deposits the sand on one of the two conveyor belts extending the length of the excavator. The sand then moves to the system which conveys it to the extraction plant.

The Syncrude plant is the world's largest oil sands mining and upgrading complex. There the oil sand is mined by four walking draglines with the capacity to move 91.5 million tonnes a year of oil sand and waste material. The draglines operate by dropping a scoop-like bucket into the sand and dragging it back toward the machine. The bucket is lifted, the boom from which it hangs swings around, and the bucket is emptied on to a long pile of sand called a windrow. From the windrow the oil sand is carried to the conveyor system by bucketwheel reclaimers, similar to the mining machines used by Suncor, but twice as long.

The oil sands mining equipment must handle large volumes of sticky, highly abrasive material in a wide range of temperatures and conditions. Some of this equipment has been adapted to the rigours of oil sands mining from its intended use for coal mining, as in the case of draglines, which are used extensively in open pit coal mines. These draglines at first had very poor maintenance records in oil sands applications, showing both structural and mechanical design deficiencies. To address these problems, dynamic stress measurement techniques had to be developed by the mine operators so that the causes of the failures could be understood and appropriate remedial actions taken.

Operators often work with suppliers in ensuring that equipment meets the site-specific needs of the oil sands mines. For example, rubber products are a major investment in oil sands mining plants: at Syncrude, conveyor belting alone is worth $20 million. In 1978-79, however, during the first full winter of operation, rubber belting supplied to a specification of brittle failure below -54^{o}C was failing in service at -40^{o} C. Because of these problems, Syncrude developed a service test and studied the influence of oil sand on the failure properties of belts at low temperatures. The results of this work have been used by the belting industry in designing new products suitable for long term service in oil sands.

Any modifications or re-designs that reduce equipment down-time will improve utilization and decrease operating costs.

Bitumen Extraction from Mined Oil Sands

From the mine, the oil sands ore is moved by conveyor belt to the plant where the bitumen is extracted from the sand.

The Alberta oil sands are hydrophilic or water wet: each grain of sand is surrounded by an envelope of water, which in turn is surrounded by oil. It is this feature that makes the hot water separation process used at both Suncor and Syncrude practical.

The oil sands ore is mixed with hot water, steam, and a caustic, such as sodium hydroxide, and raised to a temperature of about 80^{o}C so that small globules of bitumen form. Rocks, clay, and oil sand lumps are removed from the thick liquid slurry which is pumped into separation tanks. The bitumen rises to the surface as a froth and the sand sinks to the bottom, to be pumped away along with excess water. The "middlings", that is, the mixture of clay, bitumen, and water which lies between the floating bitumen froth, and the clean sand on the bottom, is removed, and the remaining bitumen is extracted from it in a second froth flotation treatment.

Naphtha is used to dilute the heated bitumen, from both the primary and secondary separation treatments, in order to make it flow more easily. The coarse solids and the clays with the remaining water are removed in two stages of centrifuging and pumped to tailing ponds. From the centrifuge, the clean bitumen is passed through a diluent recovery unit to remove the naphtha, which is returned to the process. Heated tanks store the bitumen awaiting upgrading.

Improvements in bitumen extraction are focussed on two major areas: 1) the existing hot water process; and 2) new extraction methods.

Modifications to the hot water process are aimed at reducing the size of tailings ponds, extracting bitumen from tailings, and increasing the rate at which solids settle out of process water.

The tailings stream is the largest stream in an oil sands plant, producing a stable sludge of fine clay particles in water. The Kruyer Process to recover bitumen from tailings pond sludge is being piloted-tested at Suncor Inc., where it is expected that overall recovery in the hot water process could be increased by several percentage points. Currently a one tonne per hour pilot plant is operating. Removal of hydrocarbons from the sludge could also enhance compaction and ultimately reduce the size of tailings ponds. Development of the process to commercial scale is planned for completion by 1988.

The hot water process now in use only recovers bitumen efficiently from better quality oil sands, that is, those with a bitumen-to-sand ratio between 9% and 15%. New processes to replace hot water extraction are therefore sought which will be relatively insensitive to the grade of the oil sands feed. One of the promising new technologies is the Taciuk Process, named after its originator, W. Taciuk of UMATAC Industrial Processes Ltd. The process produces a damp, oil-free tailings that can be dumped directly back into the mined-out areas of the pit, thus eliminating the need for tailings ponds. It accepts a wide range of oil sand feed grades and produces an oil product that could be pumped to a remote central refinery complex for further upgrading. Disadvantages of the process include the concentration of sulphur dioxide in the flue gas, the production of an off-gas diluted by combustion gas resulting in more complex downstream gas treating and separation equipment, and possible dust problems in the tailings area. Negotiations are underway between AOSTRA and industry for a 90 tonne per hour demonstration project. If the demonstration phase is successful, the process may become commercially available. It is unlikely, however, that it will be used unless new oil sands mining operations are established.

Another new extraction process, Solvent Extraction Spherical Agglomeration, has been developed by the Chemistry Division of NRC. This process would also eliminate the tailings pond, as well as providing increased recovery efficiency. A small scale pilot plant has been operated and a 10 tonne per hour plant is planned. This process could be added on to the tailings stream, thus increasing efficiency in an existing plant. Similarly, a solvent extraction process developed by Dow Chemical Canada Inc. and Kellogg-Rust Synfuels Inc. could also be used for expansion of existing facilities. Although solvent extraction has been well-explored, especially in the food industry (cottonseeds, soybeans), extensive modifications have been required for oil sands applications.

In addition to the extraction processes themselves, technological opportunities exist for simplifying the equipment used in handling the large volumes of abrasive slurries in theplant. Equipment companies could work with operating companies to produce simpler, more reliable equipment. Basic research is still required in the fundamental chemistry and physics of extraction in order to improve the design and operation of extraction equipment.

In Situ Recovery of Bitumen and Enhanced Recovery of Heavy Oil
The oil contained in oil sands and heavy oil reservoirs lacks mobility because of its high viscosity, and the reservoirs lack natural drive energy. Heat must be applied to make the oil fluid enough to flow, and pressure must be added to make it move through the reservoir to wells where it can be pumped to the surface.

Only about 3% of the total bitumen in place in the Alberta oil sands is accessible through surface mining, but an additional 17%, under 200 metres or more of overburden, is recoverable by special *in situ* techniques. Similar techniques are used in developing heavy oil reservoirs.

Pilot projects in heavy oil and oil sands determine the environmental and economic suitability of various recovery schemes, testing well completion procedures, trying out equipment, developing operating methods, improving techniques for separating oil and water, and studying metal corrosion. In 1985, there were forty-seven active experimental projects in the Alberta oil sands, and twenty-two active experimental heavy oil projects in Alberta. There were eighteen enhanced heavy oil projects in Saskatchewan.

There are two main methods of *in situ*/enhanced recovery: steam and combustion. Steam is better understood and is less costly, but it is expected to recover only a small percentage of the bitumen in place. Combustion may be more efficient and it delivers a partially upgraded product, but it is more difficult to control. No one method is suited to all deposits because the viscosity of the oil and the composition of the deposits vary: the success of a technique in one reservoir only indicates that the same method may work in other, similar reservoirs.

By far the best understood and most widely employed techniques are those using steam. The two new oil sands projects that came on stream in 1985, BP-Petro-Canada at Wolf Lake, and Esso at Cold Lake, are both steam recovery projects. The are two types of steam recovery are cyclical injection and continuous displacement.

Cyclical steam injection is also called "huff and puff" or steam soak. The steam is generated at the surface and injected through a well into the rock formation for several weeks to heat up the reservoir. This is followed by a soak period during which no more steam is injected. The well is then put into production. The main function of this method is to reduce the viscosity of the oil, but it can also be used as a diagnostic tool in determining the suitability of the reservoir for a continuous steam injection program. The cyclic steam method is often not suitable for the thin reservoirs typical of many heavy oils in Western Canada.

In continuous steam injection, also known as steam drive or steamflooding, steam is injected into the reservoir through a central well. Pressure and temperature force the heated oil to flow away from the injection point to production from surrounding wells. This method increases reservoir drive, decreases viscosity, and has a distillation effect on the oil. There are two limiting factors, however, depth and reservoir thickness. In order to maintain the critical pressure of the steam, the depth has to be less than 1500 metres. The thickness of the reservoir has to be greater than 3 metres because of heat loss to rock, above and below the reservoir.

The problem of deep reservoir heat loss was addressed in recent years by the development of downhole steam generators (DSG). These were extensively tested by industry and government, especially in the U.S., but the equipment failed to meet expectations. There was evidence of good reservoir response, but there were problems with corrosion and equipment failure. Poor field results and dropping oil prices have contributed to the lack of interest in the DSG. Only one is still on the market, manufactured by Rockwell, but no field tests are planned. There may, however, be opportunities for future applications in the offshore, particularly off California.

In either cyclical or steam injection, the effectiveness of the procedure can be significantly reduced by heterogeneous sand streaks or channels within the formation. These channels may allow the steam to bypass or override the less mobile heavy oil, thus seriously reducing production. Flow control techniques using surfactant foams, inert gases, or other materials as blocking or diverting agents are designed to prevent steam loss or premature breakthrough. Research is being done on developing foam additives stable enough to work during continuous displacement without plugging the formation. Research on foams also includes using them in combination with inert gases, often combustion gases, or encasing the foam in polymer gel capsules. Foam additives are gradually gaining wide acceptance in commercial field operations, but careful control is required for maximum foam life and minimum adsorption to reservoir rocks. Improved steam injection through the use of chemicals such as carbon dioxide or flue gas has been accomplished in the field; for example, Bow Valley Industries and AOSTRA have used superheated CO_2 and steam in the Cold Lake area. However, gas additive processes may have only limited application in the Cold Lake deposits because of the relative quantity of dissolved gases in the reservoir.

The generation of steam is a major cost in the use of steam *in situ* techniques so technologies that would reduce this cost are of great interest. These techniques include wet air oxidation, and the use of low-cost solid fossil fuels rather than bitumen or natural gas. Research is also underway on increasing the steam generation capacity in a single boiler. New control technologies are being used at Wolf Lake and Cold Lake to reduce the cost of fuel used to generate steam.

The other major *in situ* technique is combustion or fireflooding. Oxygen is injected into the reservoir to burn the oil underground: the fire acts as both a mobility and a distillation agent, and the resulting coke residue provides the fuel for the continued burning of the oxygen.

At the present time, fireflooding is in limited use because of high costs and operational uncertainties owing to high air-to-oil ratios, corrosion, and well completion problems. It is, however, more practical than steam for thinner reservoirs because the air being fed into the well goes in cold and there is less heat loss to overburden and surrounding rocks. Two modifications to the dry combustion method, that is, wet and partially quenched combustion, offer significantly better recovery but are still in the experimental stage. In the Lindberg field in Alberta, there is an experimental project using LPG and CO_2 with *in situ* combustion.

A novel method of preheating an oil bearing formation has been proposed using electric heating. Electrodes would be inserted into the deposit through wells and a high voltage current introduced. Resistance to the current's passage through the rock creates heat which thins the bitumen. Air or steam then has to be injected to force the bitumen to flow to a collection point. Considerable innovation would be necessary to bring this method to commercial scale and the cost of electrodes would have to decrease substantially.

All thermally enhanced recovery processes produce highly stable water-in-oil emulsions which must be treated before the oil can be pipelined. Fireflood techniques produce emulsions which are particularly difficult to break. The water must be removed using large quantities of expensive chemicals, but the actions of these chemicals are not well understood, making it difficult to optimize separation methods. Research is currently being done at universities, in industry, and at ARC and SRC on characterizing and treating water-in-oil emulsions.

Non-thermal methods of enhanced recovery are also under development, but these generally have limited application in heavy oils and are not suited to oil sands deposits. CO_2 rich gas from a gas plant is being used in an experimental project southeast of Calgary in a reservoir containing 23° API oil. The CO_2 is expected to work well because of its high density at the low reservoir temperatures. Microbially enhanced recovery is a non-thermal method in the early stages of development. Bacteria can contribute to the production of gas pressure, surfactants, and polymers, selectively plugging the reservoir to control water flow, which is a major problem in heavy oil recovery.

In addition to the *in situ* extraction/recovery methods themselves, research is underway in related areas aimed at improving the effectiveness of these operations. AOSTRA is setting up an Underground Test Facility (UTF) designed to develop and demonstrate horizontal well recovery processes for oil sands applications using the Shaft and Tunnel Access Concept (SATAC). Tunnels would be constructed in or just below pay zones and *in situ* recovery techniques would be applied through horizontal wells drilled from the tunnels. The advantages of this technique over the use of wells drilled from the surface include: more effective use of heat, lower cost of drilling horizontal wells, and the use of gravity to assist drainage. Horizontal drilling technology has improved heavy oil recovery under steam stimulation in California.

While most of the technology and equipment to drill horizontal wells from underground exist, innovation and modification are required to improve the efficiency of drills, pressure control equipment, and methods of running and cementing casing, and to develop new fast and reliable non-magnetic direction surveying systems. AOSTRA is seeking industry support for the operating costs of the UTF, but has thus far been unsuccessful. The larger companies, such as Esso, are already in the forefront of horizontal drilling technology and may not see the need for participation in the facility.

Another areas of research is in fracturing methods to open up passages for bitumen to flow through the oil sands. The standard technique of hydraulic fracturing is not always successful, thus reducing sweep efficiency and oil recovery. At the Universities of Alberta and Manitoba work is being done on explosive dynamic methods to generate horizontal fractures in deep and intermediate reservoirs.

Bottomhole instrumentation is used for moinitoring pressures and temperatures during *in situ* and enhanced recovery operations. These instruments must operate in severe conditions of high temperatures up to $400^{o}C$ and corrosive wellbore fluids with high sulphide and chloride concentrations. The instruments must be able to provide accurate measurements in tight wellbore clearances during any stage of operation and they must be easy to install and to operate. No completely reliable method of measuring bottomhole pressures now exists, but new methods are being tested and more effective devices are being developed.

Reservoir conditions also cause problems for lifting systems for heavy oil. Sand is carried with the oil into the production well causing abrasion and pump wear, and resulting in low production efficiencies and high operating and maintenance costs. A joint industry - AOSTRA program has developed three new pump designs, two of which are in use in different applications, and a third one which is to be field-tested. Sand control problems in production wells have generated research on filters at the Alberta Research Council, because of the inadequacy of existing sand control techniques. A "sandwich filter" has been patented by ARC and is being field-tested.

Important environmental considerations in the *in situ* projects are the limited supply of fresh water available in heavy oil regions, and the large amount of water co-produced with oil in these operations. The AOSTRA/Industry Produced Water Treatment Study is evaluating and selecting the most technically suitable and cost effective water treatment systems. Research on recycling water is aimed at the problem of fresh water supply.

Upgrading of Bitumen and Heavy Oil

Although there is a surplus of heavy oil production worldwide, opportunities exist in Canada to increase capacity in upgrading and refining of heavy crudes. The upgrading of bitumen and heavy oil to lighter oil would allow these heavy crudes to be used as feedstock for most Canadian refineries. Synthetic crude in Canada is now produced from bitumen at the two existing oil sands plants, Suncor at 9,000 cubic metres per day, and Syncrude at 17,000 cubic metres per day. Most Canadian heavy oil is marketed in the United States, either for asphalt or for use in refineries there, and the balance is used in Canada for asphalt.

Upgrading lowers the viscosity of heavy oil so that it can be transported through pipelines and increases the hydrogen to carbon ratio in order to bring the hydrogen level up to that of conventional oil. Increasing the hydrogen to carbon ratio may be done either by reducing the carbon content or by increasing the hydrogen content. A number of variations on these two techniques are being marketed, but not all have been proven on a commercial scale for heavy oils and/or bitumen. Some have been used for upgrading the residuum in conventional refineries; others have been tested only at pilot plant scale. The individual processes have been are developed and licensed by a variety of organizations including oil companies, e.g. Esso; engineering firms, e.g. C-E Lummus; suppliers, e.g. Engelhard Corp.; specialized firms such as Hydrocarbon Research Inc.; and governments, e.g. CANMET.

Although the carbon removal processes, called "coking", are well proven and successful, no new upgrading units of this type are planned in Canada. All three new upgrading plants expected to come on stream by the end of this decade will use hydrogen addition processes because of the higher liquid yields from these processes and the serious coke disposal or coke marketing problems with the coking processes.

Historically, oil sands bitumen upgrading has relied on carbon rejection processes, specifically, delayed coking and fluid coking. In 1967, when the Suncor plant (originally Great Canadian Oil Sands Ltd.) was built, few alternatives to delayed coking were available commercially. For conventional oil, the process had been used in Canadian refineries and elsewhere with high quality distillation residues, yielding a low sulphur marketable coke and large quantities of lighter products. The Suncor coke has, however, a high sulphur content and a high concentration of metals, severely limiting its marketability, and although the plant uses the coke as boiler fuel, production far exceeds the amount required. About one-third of the coke production has to be stockpiled and may eventually have to be buried.

Fluidcoking, developed and licensed by Exxon, was chosen by Syncrude because the process yields 6% more fluid and much less coke than delayed coking does. About 40% of the Syncrude coke is used for reactor heating and the rest is slurried and piped to storage ponds. Fluidcoking was already a well-demonstrated, technically reliable process in other applications when Syncrude selected it, yet many technical problems were experienced at start-up because of the novel application to bitumen upgrading.

Flexicoking is another process developed by Exxon as an extension to Fluidcoking. Insensitive to feedstock variations, it yields gas oils, lighter products and, instead of coke, a clean low-BTU coke gas. The coke gas, however, requires increased investment and operating costs for burning it, rather than conventional fuels. Both Exxon processes have been extensively demonstrated commercially worldwide: there are three operating Flexicokers, two under construction, and twelve operating Fluidcokers.

The Eureka process, available under licence from Mitsui and Co. Ltd., is an extension of delayed coking, but produces pitch rather than coke. The process was developed in Japan, proven in a 3000 cubic metres per day plant ,and tested on pilot plant scale with oil sand bitumen and Canadian heavy oils. No information has been released on the quality of the pitch produced or the scale of the disposal necessary.

A process associated with coking is licensed by Kerr-McGee. Called ROSE, Residuum Oil Supercritical Extraction, it uses solvents to separate the oil fraction, reducing the residue for coking treatment by about one-half. The process has been in commercial operation since 1979 with units built in locations where the solid residue (asphaltene) can be sold as asphalt. If such a market is not available, however, a coking process has to be included in the system. The advantage of ROSE is that a smaller unit can be built.

The major problem with the coking processes in use is evidently the large volume of coke produced. Research is underway on finding ways of reducing sulphur dioxide emissions from burning this coke. ARC and AOSTRA have a joint project in this area.

The main alternative to coking is the hydrogen addition technique of hydrocracking. Hydrocracking involves heating the heavy oil with hydrogen under pressure in the presence or absence of catalysts or additives. High pressure operation and substantial hydrogen requirements are common to most hydrocracking operations, but reactor arrangement and catalyst use may differ.

Unlike coking, the hydrocracking process makes potentially all the heavy oil available for conversion to synthetic crude. The disadvantages of the process are the higher capital costs associated with high pressure and temperature reactors and vessels, higher operating costs because of hydrogen usage and catalyst addition (if used), and a possible disposal problem with the unconverted residuum or bottoms stream. When a hydrocracker is added to a plant with an existing coker, however, this last problem can be eliminated by feeding the hydrocracker bottoms to the coker.

Thermal hydrocracking uses no catalysts so the operation is relatively simple, there is more operating flexibility, and there is no process cost associated with catalyst availability. Also, with no catalysts, it is not necessary to maintain fluidized beds of solids. The disadvantage is that achievable conversions are lower with thermal processes.

During catalytic hydrocracking, the catalyst absorbs metals and coke from the oil, thus becoming deactivated or "poisoned". The spent catalyst must be disposed of or treated before being used again. An upgrader produces tonnes of spent catalyst every day so purchasing, handling, and processing can be very expensive. In addition, the only catalyst processing facilities are in the U.S. The development of fouling-resistant catalysts would provide major process improvements.

There are a large number of hydrocracking technologies marketed under various trade names. Not all have been used for upgrading oil sands bitumen or heavy oils, and some are more suited to certain qualities of oil. Some require further processing of the hydrocracked product. The following list provides examples of processes and licensors; it is not a complete listing. Note that H-Oil and LC-Fining are basically the same process.

Process/Licensor

ART (Asphalt Residual Treating) / Engelhard Corp.

Aurobon / Universal Oil Products Co.

CANMET / Partec-Lavalin and Petro-Canada

Chiyoda / Chiyoda Chemical Engineering and Construction Co. of Japan (only tested at bench scale)

H-Oil / Hydrocarbon Research Inc. with Texaco

HDM/H CON / Shell

LC Fining / CE Lummus with Cities Service

Veba-Combie / Veba Oil (West Germany)

A new technology of particular interest is the CANMET process, developed by the Canada Centre for Mineral and Energy Technology in the federal Department of Energy, Mines and Resources. The process is aimed at heavy oils with high asphaltene, sulphur, and metals contents. It uses an additive as an inexpensive catalyst substitute which suppresses coke formation and destroys metals while producing lighter products from heavy ends. The additive is a mixture of finely ground coal and iron sulphate. The advantages which are claimed for the CANMET process over competitive processes include:

- feedstock flexibility: no catalyst means less sensitivity to metals and sulphur;
- lower operating pressures than for H-Oil/LC Fining;
- better conversion rates: yield of 90% or more, compared with 60% for H-Oil/LC Fining.

The complete destruction of metals would make the CANMET process particularly attractive for use with California heavy oils.

Exclusive rights to commercialise the process were negotiated with Petro-Canada, which then reached an agreement with the engineering firm Lavalin Inc. to share the licence and build a demonstration unit at Petro-Canada's Montreal refinery. Commissioning the 780 cubic metres/day plant began in September 1985. Having much of the process design and all the engineering carried out in Canada by a Canadian firm has established that firm as a supplier to operators of such upgrading units as well as to other users of related processes and equipment.

Associated R&D on techniques for welding heavy wall pressure vessels required for the Petro-Canada facility was also done through CANMET.

As an extension to its hydrocracking process, CANMET has developed a co-processing technology to produce liquid products from heavy oil, bitumen or residual oil and up to 50% coal. The oil is upgraded at the same time as the coal is liquefied, which offers a more practical route to synthetic crude from coal than through direct coal liquefaction. The process has been successfully demonstrated on a bench scale, and negotiations are now underway for an 8 cubic metres/day co-processing unit. Canada is a world leader in this technology.

There are three new projects planned to increase upgrading capacity of bitumen and heavy oils in Canada by 1990 but none of them uses new technology. Two projects, the Bi-Provincial Upgrader of Husky Oil and the Syncrude expansion, will be using the same technology under different names, H-Oil and LC-Fining respectively, and the third, the NewGrade Energy Inc. upgrader in Regina, will be using a hydrotreating process.

The Husky Oil upgrader at Lloydminster, Saskatchewan, will produce 8,600 cubic metres/day from heavy oil reservoirs in Lloydminster, and from Lloydminster/Cold Lake reservoirs in Alberta. Under the agreement signed in 1984, the federal government would provide a $50 million grant and a $780 million loan guarantee, and Alberta and Saskatchewan each would provide $390 million in loan guarantees.

In April 1986, the federal government agreed to contribute $36 million in 1986 towards the $90 million pre-engineering costs of the upgrader. Husky Oil Ltd. will pay $27 million, and the remaining $27 million will be funded by the governments of Alberta and Saskatchewan.

The original 1983 proposal for the upgrader called for Flexicoking to be used as the upgrading technology because of the relatively low technical risk at acceptable operating costs. However, pilot plant testing proved that ebullated bed hydrocracking was practical for Cold Lake bitumen, so in 1985 low-conversion H-Oil hydrocracking was chosen for use with delayed coking. H-Oil was selected because it has been proven commercially in operations in the U.S., Kuwait, and Mexico, and it offered a good financial yield at acceptable technical risks. The problems associated with catalyst poisoning and recycling are being addressed in research programs.

In 1983, Syncrude announced a $1.2 billion five-year program to expand production and improve efficiency, including plans for a new bitumen hydrocracker and associated units. Production of synthetic crude will be increased by 4800 cubic metres/day over its current level of 17000 cubic metres/day.

The process selected by Syncrude, virtually the same as that chosen by Husky, is LC-Fining. The hydrocracking unit will be used in tandem with the plant's two existing fluid cokers which now do all the upgrading. In the new arrangement, hydrogen will be added to the bitumen in the presence of a catalyst, producing synthetic crude and a pitch-like substance. The pitch, in turn, will be fed to the cokers for upgrading to synthetic crude. The major yield improvement will result from the reduction in coke and gases produced from the Fluidcoking process. An advantage of this arrangement is that the expansion in upgrading capacity could be repeated by adding hydrocrackers upstream of the fluid cokers.

NewGrade Energy Inc., a partnership between the Consumers' Cooperative Refinery Ltd. in Regina and the Saskatchewan government, will use a hydrogen addition process developed by Union Oil of California to produce about 4800 cubic metres/day of upgraded oil from a blend of medium to heavy Saskatchewan crude oils. The process is a residuum hydrotreating process which is not a new technology. The upgrader will cost about $600 million and will be onstream by 1988. The existing refinery will use most of the upgraded crude.

All upgrading processes for bitumen and heavy oils produce residues with varying concentrations of contaminants. These residues must be treated in an environmentally acceptable and economic manner. AOSTRA, industry, and the federal government are carrying out a multi-phase project to identify, evaluate, and test the most promising technologies for use on such residues.

AOSTRA is also considering the possible use of oil sands bitumen as cracking feed for the manufacture of petrochemical starting materials, such as ethylene, which are expected to become scarce and expensive. The opportunity to increase the value of bitumen over that from processing synthetic crude for transportation uses is significant. Data has been acquired from Japan on testing a direct thermal cracking technique for the production of ethylene and other petrochemical feedstocks from bitumen. These data will be made available to Alberta companies interested in pursuing such technology.

While the development of new upgrading technologies continues in government and industry, the rate at which these technologies are commercialised depends not only on the price and availability of conventional oil vis-a-vis heavy oils, but also on the willingness of operators of new facilities to use technologies which have not been commercialised, and on the rate at which new facilities are built. Without capacity expansion, there will be no markets for new upgrading technologies.

Information Technologies

Information technologies support all phases of oil sands and heavy oils development from planning through production to upgrading. Generally, these technologies are not unique to this sector, but are borrowed or adapted from the mining, conventional oil and gas, and refining industries.

Modelling is a major application of information technology in oil sands mining, in enhanced recovery of heavy oils, and *in situ* recovery of bitumen. Modelling of oil sands deposits is important in evaluating, planning, and simulating development, and it facilitates the updating of reserves and geological information. It is a valuable tool for economic cut-off criteria determination, reserves analysis, preliminary mine design, and feasibility studies. The technique of Block Value Modelling was developed in the mining industry for accurate representation of mineral deposits and has proven to be applicable to oil sands deposits as well. Various modelling packages are available commercially but may not be practical in all cases; in-house development of models is sometimes necessary.

The Computer Modelling Group, an industry-supported organization in Calgary, offers a variety of models concerned with enhanced oil recovery. Although not specifically designed for heavy oils, these models may be adaptable for heavy oil reservoirs to simulate performance.

Other software packages have been developed for specific oil sands and heavy oil applications. For example, there is an industrial application-oriented program available to describe *in situ* fracturing behaviour of oil sands formations. In another case, a heavy oil estimating program has recently become available as a tool for engineers and managers to assist in planning new or expanded heavy oil facilities. The program can address "what if" scenarios and has a computer-aided design system linked with it.

AOSTRA is actively supporting information technologies through several avenues. It offers a data base management system for use by companies involved in *in situ* pilot projects: the system includes full data storage, access, and reporting. Through licensing arrangements between AOSTRA and the individual user companies, system charges are related to the volume of data and the amount of use.

Syncrude and AOSTRA together are developing a computerized regional Air Quality Prediction System to forecast air pollution levels in the Fort McMurray area up to eight hours in advance, so that action can be taken to prevent those levels from exceeding provincial standards.

AOSTRA also supports the Alberta Oil Sands Information Centre at the Alberta Research Council (ARC). The centre collects and disseminates information related to oil sands, heavy oils, and enhanced recovery, and publishes quarterly the Alberta Oil Sands Index (AOSI) and the Heavy Oil/Enhanced Recovery Index (HERI). Both AOSI and HERI are available on line. In addition, ARC maintains an on-line Oil Sands Researchers and Projects File and a numerical data base on the physical properties of oil sands.

In the area of control systems and instrumentation, expansions to existing facilities and the development of new projects are enabling companies to take advantage of the newest technologies available. As part of the five-year Syncrude expansion program, for example, a new state-of-the-art computerized Utilities Advanced Control System is being installed. Other examples of new technology include:

- a field-oriented microseismic array for monitoring the progress of *in situ* oil sands and heavy oils recovery processes;

- solid-state electronic controls for optimizing oil pumping operations;

- newly developed instrumentation at the Esso Cold Lake project to control the combustion process for steam and maintain optimum efficiency: includes sensors, analyzers, calorimeters;

- transponders to monitor and control the use and movement of equipment to improve efficiency in oil sands mining operations.

The effective use of new technologies is essential to the growth of the heavy oils and oil sands industry. With the expansion of existing facilities, the large number of pilot projects, and the proposed new upgrading facilities, the opportunities are there for companies to continue to exploit the latest technological developments.

C. PIPELINES

In Canada, there are over 216,000 km of pipelines carrying oil or natural gas. Most are in southern Canada, moving oil and gas from the West to Central Canada and the United States. The major exception is the recently completed crude oil pipeline from Norman Wells, NWT, to Zama, Alberta. Approximately 85% of Canadian pipelines are for natural gas with the remaining 15% carrying crude oil and refined oil products.

The Major Projects Inventory, issued by the Department of Regional Industrial Expansion in October 1985, forecasts about $22 billion worth of pipeline projects between 1985 and 1995. Some of these projects are already underway, such as the crude oil pipeline system expansion in Western Canada, but most northern and offshore pipelines have been postponed because of the weak markets for natural gas and lower oil prices.

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

Pipeline Design
Pipelines are designed to achieve optimum operational efficiency, considering the commodity being transported, the distance over which it must be moved, and the environment through which the pipe must pass.

Higher operating pressures would offer a significant improvement in pipeline operational efficiency, but an express line at high pressures would require a new generation of pipeline design. Special steels with increased yield strength would be needed to allow reduced pipe diameters and thinner-walled pipe to carry the same volume throughput at the greater operating pressures. This innovation would be of particular interest to pipeline companies planning large scale northern pipelines.

Other opportunities for Canadian steelmakers exist in improving the performance of steel in pipe for sour gas and for transporting other commodities such as anhydrous ammonia or carbon dioxide, which is used in enhanced oil recovery. The Canadian steel industry is very active in research on linepipe and is internationally competitive in this area.

Considerable R&D is also underway on corrosion of materials, especially in offshore applications, and on pipe coatings to reduce damage during handling.

Construction
Construction accounts for about 40% of the cost of any major pipeline project. An important element of the construction process is welding, because it generally sets the pace for other pipeline construction

activities. Increased efficiency in the welding process would therefore provide substantial benefits in terms of scheduling and consequent cost savings. However, it is not only the rate but also the quality of the welding that is important. Advances in automatic arc welding and high-impact (explosive) welding are providing improved weld qualities. Welding is a major focus of pipeline-related R&D across the country.

Another important aspect of the construction phase is the transportation of pipe to the site. As projects are planned and constructed in more remote locations, transportation becomes an increasingly significant proportion of pipeline installation costs. The possibility of using lighter-than-air modes such as dirigibles, is being seriously considered. On the ground, longer railway cars and self-steering pipeline transporters for highways and rights-of-way could permit longer sections of pipe to be moved. This would not only reduce transportation costs, but could also increase the rate of pipeline installation by decreasing the number of field welds required.

Compressors and Pump Stations ("Prime Movers")
In order to move oil or gas through a pipeline, adequate pressure is required. In oil pipelines, pressure is supplied by pumps (reciprocal and centrifugal) located in pumping stations; in gas pipelines compressors do the work. Most compressor stations use gas turbines developed in the aircraft industry; the remainder use standard industrial turbines.

The largest single component of pipeline operation cost is fuel for compressor and pump stations: it can be as much as 10% of total volume throughput. Interest in greater fuel efficiency has resulted in improvements such as waste heat recovery and continuous cycle operation. Further improvements in compressor efficiency, including improved electric drive, are continually being sought.

Other future developments in prime movers include: automatic feedback for control using microprocessors better able to withstand the environment of the compressor station, expert systems for optimization of compressor types, and fully automated station operation for northern and remote sites, using satellite communications.

Compressors and pumps are not unique to the pipeline industry, however, and technological advances will likely arise from developments for other applications with a wider market. Canada has a large healthy industry dominated by subsidiaries of foreign-owned companies producing prime movers. There is considerable R&D done in Canada in this field.

Inspection
Inspection is a key element in the maintenance and safe operation of pipelines. As pipelines age, inspection becomes important in identifying sections of pipe that must be replaced. Technological development must focus on increased sensitivity of inspection methods to improve the detection of corrosion and cracks.

Internal inspection is carried out in only about 50% of the world's pipelines. Older lines are not amenable to this method because the pipes were not constructed with launchers for electromagnetic inspection devices ("pigs"), or with valves through which the devices could pass. To address this problem, R&D is being conducted on magnetic methods of detecting pipeline defects by remote measurements.

R&D is also being carried out on a device to measure stress in pipes. This would enable identification of sections where frost heave might be occurring so that action could be taken to avert possible failure. Such a device could be attached to electromagnetic inspection equipment.

R&D on all aspects of pipeline inspection is being done not only by the instrument manufacturing companies, but also by the pipeline companies themselves because of the importance of safety in pipeline operations.

Metering, Control, and System Optimization

Opportunities for improvements in metering and control systems include: on-line systems controls, remote operations controls, remote strain gauging, remote cathodic protection monitoring, better means of monitoring and controlling water emulsions in oil pipelines, and improved communications lines through the use of fibre optics for operating control systems. Meters are a special area of concern as the conventional orifice meters cause pressure drops in the pipeline. Increasingly, high pressure turbo flow meters and vortex shedding meters are being used.

For overall system optimization, expert systems and improved data acquisition techniques are needed. A new technology with great potential for improving the efficiency of pipeline operations is two-phase flow, that is, moving oil and gas through the same pipeline at the same time. Multi-phase flowmeters are being developed for this application.

Permafrost

Many of the foregoing technological requirements are applicable to pipelines built in any environment. In the case of permafrost, there is the added need for continued basic research on the mechanisms of heat and mass flow in frozen soils, on the direction and magnitude of forces against a buried pipe, and on the location and types of subsea permafrost. These questions are being addressed through R&D in NRC, EMR, industry, and universities.

The pipeline from Norman Wells, NWT, to Zama, Alberta by Interprovincial Pipe Line (NW) Ltd. was the first large, fully buried oil pipeline to pass through areas of permafrost. The line was specially designed to limit thermal inputs to the surrounding soil, and it incorporated increased pipe strength to withstand the additional loadings caused by thaw settlement. The experience gained in the construction and operation of this new line will offer valuable guidance in the design of future northern pipelines.

Offshore Pipelines
As with permafrost, the offshore environment is an important additional factor over and above other technological challenges to be considered in the design of new pipelines. In particular, in the Canadian offshore, the problem of ice scouring the seabed continues to demand attention. Mechanical models of ice-seabed interaction have been developed to estimate scour dimensions and soil pressures caused by the grounding of a given ice mass. Research has shown that trenching appears to be the most effective protective measure for submarine pipelines, but the optimal trench depth can be reduced by valve segmentation, that is, valves placed at frequent intervals, which can shut off the flow quickly and completely should a break occur. Research is still required to ensure that the most economic means is available for transporting oil and gas in the offshore while minimizing risks to the environment.

Slurry Pipelines
Pipelines can be used to transport solids such as coal, ore concentrates, potash, wood chips, and sulphur when these substances are mixed with a liquid such as water, methanol, or oil to form a slurry. The technology is well advanced, with a number of large systems operating successfully around the world. There are no long-distance slurry systems operating in Canada but there are many short-distance in-plant lines which have operated since the early 1900's.

R&D in slurry pipelines has focussed on moving coal through pipelines. Techniques investigated have included: coal/water mixtures, metallurgical coal slurries, coal/ water/ chemical gel slurries, and coal agglomeration. The Saskatchewan Research Council is the major centre for slurry pipeline research and is acknowledged worldwide for its expertise in this field.

No large scale slurry pipeline projects are being planned in Canada. In the U.S., no slurry pipelines are now under consideration either partly due to lack of markets, but also due to strong opposition from railway companies.

Summary
Technology can improve pipeline transportation by directly reducing the capital costs of projects and by improving the efficiency of the operating systems. The major opportunities for innovation in these two areas are:

- steel development
- construction technologies, particularly welding
- inspection technologies
- prime mover improvements
- metering, control, and system optimization
- understanding permafrost behaviour and its interaction with pipelines
- understanding ice and seabed interactions

The market for pipeline technology is worldwide and any advances that

Canadian companies may make could be translated to the much larger market in the U.S. and abroad.

Pipeline R&D and the Regulatory Environment

Oil and gas pipelines are utilities and as such are regulated by the National Energy Board. Other agencies that have also been involved in the regulation of offshore and northern pipelines are COGLA and the Northern Pipeline Agency.

Because of this regulated rate base, it has been suggested that the economic incentives for the adoption of new technology by pipeline companies may be weak. Economic benefits may only flow back to the oil and gas producers and shippers, rather than to the pipeline companies themselves, and there is the risk that the new technology may not be approved by the regulating agency, thus excluding from the rate base the cost of development and implementation of the technology.

Complaints that regulations are too inflexible to allow for technological innovation emphasize the difficulty of changing existing codes and regulations, with regulations sometimes taking precedence over CSA standards. R&D could be viewed as a means of safely relaxing standards and regulations by establishing an accurate knowledge base.

The pipeline companies themselves tend to be very conservative, however. Pipeline projects are capital intensive and are subject to tight schedules, so companies demand a significant demonstrable benefit from any proposed innovations. Operational risks are higher on express line systems such as northern pipelines, than on looped systems such as those in southern Canada. In order to gain regulatory acceptance and approval, reliability and proven technologies are emphasized. A recent article on the proposed Polar Gas pipeline boasted:

> *"The pipeline system design proposed by Polar Gas requires no unusual, unique or experimental techniques."* (Oil and Gas Journal, Jan. 6, 1986)

While this may be reassuring to regulators and investors, it does not create a supportive environment for the development of new technologies.

Canadian pipelines are more advanced technically than those in the U.S., mainly because Canadian systems are newer. If we are to maintain that level of technology, R&D must be viewed by industry as an opportunity, not just as a requirement laid upon it by the regulatory authorities.

R&D Support for Pipelines

Considerable capability exists in Canada for pipeline R&D. Facilities within industry and government enable extensive R&D to be conducted on all aspects of pipeline design, construction, and operation. R&D participants include the federal and provincial governments, universities, pipeline companies, steel companies, manufacturers of compressors and pumps, manufacturers of inspection equipment, engineering companies, institutes, and industry associations. Some Canadian pipeline companies also belong to the American Gas Association, which has a pipeline research division.

Co-operative R&D is undertaken through joint company arrangements, as well as through cost-shared programs between industry and government. The PERD program for the cost-shared development of steels for use in the Arctic and offshore has been cited by industry as an excellent example of government and industry co-operation.

Two studies, one in 1983 for Transport Canada and one in 1984 for EMR, reviewed R&D for pipelines; both concluded that the facilities and existing level of R&D were adequate. Both studies also identified a general lack of communication within industry, between industry and government, and within government, on what R&D was being done by whom. One proposal to remedy this was the establishment of an industry organization to provide a focus and direction for pipeline R&D, to improve communications between industry and government and between the oil and gas pipeline industries, to encourage cooperative funding of R&D projects and to support R&D projects, identified by the Canadian Standards Association code committees and regulatory agencies. Such an organization has not been established.

CANADIAN TECHNOLOGICAL CAPABILITIES AND REQUIREMENTS

Canadian capabilities in developing technologies required in offshore oil and gas, oil sands and heavy oils operations vary considerably. In some cases, capabilities are very strong; in other areas, while major opportunities exist, Canadian firms and government do not appear to be well positioned to seize these opportunities. A brief synopsis of capabilities in the required technologies follows.

A. OFFSHORE OIL AND GAS

INFORMATION TECHNOLOGIES

Canada has an emerging expertise in information technologies. Major changes and advances in technologies are occurring. The supplier community is relatively small and fragmented. A significant impetus for technology development has been generated through government programs such as PERD and the AMTR&D, and through the actions of individual departments such as the Department of Fisheries and Oceans. Given the potential major markets that could be available, a technology centre for ocean information technologies should be considered. Small companies should be encouraged to gain access to these markets.

MARINE VESSELS AND PLATFORMS

Strong R&D capability for ice-classed transitting vessels exists within government (AMTR&D and the Transportation Development Centre), within industry (e.g. Dome, Gulf, Esso, Canarctic) and consulting firms.

Strong domestic capability exists in the design of drilling and production structures: the oil and gas industry, engineering consulting firms and government (for regulatory requirements). Despite these capabilities, foreign firms are active in the design of structures. Fabrication facilities exist in Canada, although certain components are less expensive from foreign sources.

Canada has a leading capability in ice engineering and ice management, particularly within consulting firms, industry and government (e.g. NRC).

Materials-related expertise exists within research centres (e.g. C-FER), and within government (CANMET, NRC).

Strong capability exists within industry for sub-sea systems (e.g. CanOcean), and suppliers (e.g. International Submarine Engineering).

ENVIRONMENTAL PROTECTION TECHNOLOGIES

Canada has a very strong research capability in government, consulting firms and industry. Opportunities exist in the marketing of hardware and software systems.

NATURAL GAS MANAGEMENT
Industry has some expertise in this area, but significant efforts and breakthroughs are required.

SAFETY EQUIPMENT AND SYSTEMS
In recent years, a domestic supplier community has emerged that supplies new safety technologies. Industry and government have developed expertise and technology. This area has traditionally been dominated by foreign technologies

B. HEAVY OILS AND OIL SANDS

OIL SANDS MINING
Canada has a very strong capability in oil sands mining - Suncor and Syncrude are the only commercial plants of their type in the world. Both firms work closely with equipment manufacturers and suppliers and have major R&D programs. R&D is also performed by AOSTRA, universities, and government agencies, both federal and provincial. Much of the large equipment, however, is mining equipment manufactured in other countries.

BITUMEN EXTRACTION FROM MINED OIL SANDS
The hot water process now in use was invented in Alberta. Canada has world expertise in this technology. This is the only place in the world where this and similar processes have a major market. R&D is performed by oil sands operators, AOSTRA, universities, governments, and chemical and engineering companies.

IN SITU & ENHANCED OIL RECOVERY
Very site-specific technologies are required but are based on international technologies. Canadian industry has developed expertise and systems to meet local requirements. Major R&D programs are performed by larger companies, AOSTRA, universities, and government.

UPGRADING OF BITUMEN & HEAVY OIL
With the exception of the CANMET hydrocracking technology, Canada does not have strong expertise in this area. Domestic expertise has been developed by having a Canadian oil company work with Canadian engineering firms on a commercial-scale plant. All three new upgraders for heavy crude oils will be using U.S. processes. A central problem is the lack of markets for new processes if very few new upgraders are built or added on to existing refineries. More importantly, industry is cautious in adopting new technology, preferring to proceed with well-proven technologies. There are continued needs for demonstration-type projects, as in the CANMET project. Some Canadian capability exists in other related technologies, such as in equipment and design work, which are being encouraged through CANMET. Environmental protection

technologies are important, with R&D being performed by AOSTRA, universities; and private firms.

INFORMATION TECHNOLOGIES
Canada has a growing capability in information technologies for oil sands and heavy oils. These technologies are largely adapted from conventional oil and gas operations. A strong capability exists in universities (e.g. Queen's), government (e.g. ARC and CANMET), industry (e.g. the Computer Modelling Group and Syncrude) and in AOSTRA.

C. PIPELINES

Canada has a good capabilities in steels, and pipeline design and construction. There is, however, very strong offshore competition in steels for special applications (e.g. sour gas). Cost-shared programs exist between industry and government under PERD-CANMET auspices. A healthy industry exists in prime movers, with considerable R&D being performed in Canada by foreign subsidiaries. These companies have a market much broader than pipelines, and many of the innovations come from applications in other industries. Canadian technology is weak in innovative metering and control systems for optimization. Most of the competition is from U.S companies. This type of equipment must be made more adaptable to the pipeline industry's requirements.

Summary
Major areas requiring increased efforts in promoting Canadian capabilities or realizing market opportunities for offshore oil and gas exist in: information technologies, environmental protection technologies, and natural gas management. For heavy oils and oil sands, there are strong domestic capabilities in most areas, but some improvements are possible in upgrading of bitumen and heavy oils, and in innovative metering and control systems.

6. CONCLUSIONS AND POLICY OPTIONS

This report has described the activities of the oil and gas industry, technological support for oil and gas R&D, government policies and programs affecting the industry, and the anticipated new technologies that will be required to develop new petroleum supplies. This chapter contains a review of the main conclusions of the study, a discussion of the rationale for supporting new technologies, and identifies the barriers to, and positive influences on, the development of these technologies. Finally, policy objectives are presented and policy options to meet these objectives are forwarded.

CONCLUSIONS

The main conclusions of the study are:

1. The financial performance or strength of the oil and gas industry is a major factor in determining the development and adoption of new technologies. The performance of the industry is in turn affected by world oil prices and energy policies.

2. The Canadian oil and gas industry began a modest recovery from 1983 to 1985 following a deterioration in the investment climate in the early 1980s. By early 1986 the industry was retrenching, owing to the rapid and large drop in world oil prices.

3. The outlook for the industry is poor if oil prices are below US$15.

4. In the longer term, the outlook is positive. Prices are expected to improve, and Canada will require substantial increases in its oil and gas supplies. Oil supplies from conventional mature areas will decline substantially from present levels over the next 20 years. The development of oil sands, frontier resources, and heavy oils will be required to meet domestic demand. These sources are expensive, with costs in many cases exceeding recent oil prices, and if developed, will stimulate the development for a number of new technologies.

5. The oil and gas industry's expenditures on R&D have dropped significantly since 1981 and are not expected to improve. Of particular concern are the substantial reductions in R&D expenditures in upstream activities - exploration, development, and *in situ* R&D - since Canada's new supplies of hydrocarbons will be brought on stream through the upstream sector.

6. The oil and gas industry is closely monitored and controlled by government. The dismantling of the National Energy Program provided a positive stimulus for investment until lower world oil prices arrived. Energy policies in the future will have to address a number of issues. One concern is ensuring the

continuity in expertise and leadership in oil and gas R&D, when industry investment is sharply curtailed by economic conditions.

7. Under a scenario of higher oil prices, capital expenditures amounting to some $50 billion could be made on major projects in in the next decade, providing a positive stimulus to R&D and technology development. Significant domestic and international market opportunities have been identified for these technologies. The oil and gas industry is a potentially major user and large market for a range of technology-intensive products and services. Oil and gas projects offer the potential for achieving an intensification of technological activity through linking the oil and gas industry to the manufacturing sector and research community. A strong R&D base with close linkages to the oil and gas industry is, however, required.

8. Canada has strengths and international leadership in many technologies required for offshore oil and gas, heavy oils and oil sands. Certain barriers to technology development do exist.

9. The technologies required for the oil and gas industry are as follows:

A. Offshore Oil and Gas

- Information Technologies
  - Data Collection and Management
  - Models for Design and Decision-Making
- Marine Vessels and Platforms
  - Ice-Classed Transitting Vessels
  - Drilling and Production Structures
  - Ice Engineering and Ice Management
  - Materials
- Subsea Systems
- Environmental Protection Technologies
- Natural Gas Management
- Safety Equipment and Systems

B. Oil Sands and Heavy Oils

- Oil Sands Mining
- *In situ* Recovery of Bitumen and EOR for Heavy Oils
- Upgrading
- Information Technologies

C. Pipelines
Design
Construction
Compressors and Pump Stations
Inspection
Metering, Control and System Optimization
Permafrost
Offshore Pipelines
Slurry Pipelines

10. Canadian capabilities in these technologies vary considerably. In some cases, capabilities are very strong; in others where major opportunities exist, Canadian firms and government do not appear to be well positioned to seize these opportunities. Areas requiring increased efforts in developing Canadian capabilities or realizing market potential include: information technologies, environmental protection technologies, and natural gas management. Improvements in capabilities are possible in upgrading of bitumen and heavy oils, and in innovative metering and control systems.

In addition to these ten major conclusions, three major topics relevant to technology development are discussed in more detail in the following sections. These are:

- The Rationale for Supporting Technologies
- Barriers to Technology Development
- Positive Influences in Technology Development

Rationale for Supporting Technologies
The reasons for supporting the development of new oil and gas related technologies are to:

- ensure security of domestic oil and gas supplies,
- increase the productivity and competitiveness of the industry,
- improve industrial innovation,
- provide business opportunities for suppliers,
- generate scientific expertise,
- enhance the ability of Canadian firms to adopt foreign technologies,
- foster international cooperative projects,
- provide employment,
- protect the environment.

Barriers to Technology Development
The following barriers to the development of new technologies have been identified in this study:

- The development of Canada's oil and gas potential is sensitive to oil prices. As world prices have dropped dramatically in recent years, planning the development of new sources of hydrocarbons has become more difficult.

- Industry R&D expenditures have declined significantly since 1981 and have not followed the recovery of the industry.

- The regulatory approvals process for new oil and gas projects is perceived by industry to be onerous and discourages activities.

- The oil and gas industry is generally risk averse and takes a conservative approach to new technologies.

- R&D and innovation tend to be remote from mainstream activities of industry and government. Technology development and corporate strategies tend to be isolated.

- Limitations exist in financing of R&D and technology development.

- Difficulties persist in staffing and maintaining teams of experts.

- Limitations are inherent in the management of R&D.

- Government funding programs have certain limitations.

- Innovative Canadian firms often lack credibility and track record.

- There is insufficient use of consultation, communication, and feedback mechanisms within industry, government, universities, and research centres and between these sectors.

- In many instances, data are confidential.

- There is a lack of common data standards.

- For certain technologies, limited markets are available; there are considerable uncertainties in the development of technology; and international competitition in fabrication and manufacturing is intense.

- In certain areas, e.g. the ocean industry, a relatively weak supplier community exists (although niches in world markets have been found and successsfuly exploited). Firms supplying technology for conventional operations are well established, yet a large portion of equipment is imported.

Positive Influences in Technology Development

- The industry reinvests a substantial portion of its cash flow into operations and capital expenditures.

- While Canada has abundant supplies of oil and gas, a substantial increase in production of offshore oil, oil sands, and heavy oils to meet future demand will be required. These sources will be costly and will require new technologies. Compared to conventional oil in established areas within Canada, however, production from these sources is becoming increasingly attractive.

- Energy policies have promoted the development of these sources of supply. Historically, Canada has had a strong commitment to domestic energy security.

- Various other policies encourage R&D, and several generous funding programs are available. DRIE and NRC have effective regional delivery systems.

- A large international market exists for oceans services and hardware.

- Certain government programs (in particular, PERD and the AMTR&D) have commercialisation plans for the development of new technologies that have resulted in new opportunities for businesses.

- Certain government programs have taken a "portfolio" approach to R&D, consisting of a mix of short, medium, and long-term projects that cover various research areas.

- Government funding for oil and gas-related R&D has sustained activities through downturns in business cycles that have caused reductions in industry spending.

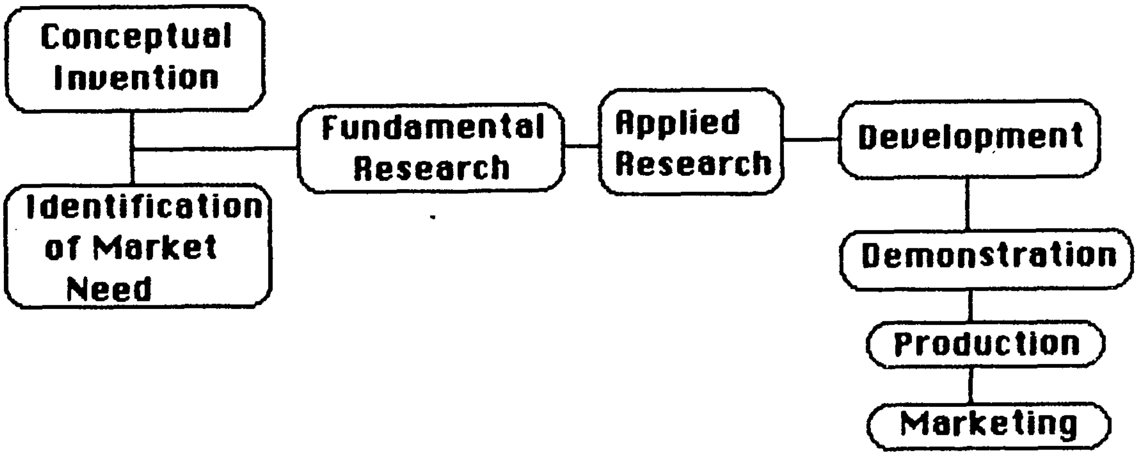
POLICY OPTIONS

The following seven policy objectives will have to be pursued if Canada is to maximize the effectiveness, relevance, and value of oil and gas R&D performed by industry, government, universities, research centres, and supplier industries.

Policy Objectives

1. **To ensure that opportunities are fully exploited, constraints or barriers to technology development are overcome, and technology development is accelerated.** Meeting this objective would improve the flow of innovation. The innovation chain or process in its simplest terms can be viewed as follows.

Figure 6.1
<u>The Innovation Chain</u>



Other central factors relevant to this process include the generation of new ideas and technologies, as well as adaptation and diffusion of new technology. A key aim of science and technology policies must be to ensure that technology transfer functions effectively and rapidly.

2. **To increase private investment in innovation.** The long-term potential of the oil and gas industry will require adequate funding for innovation. Present R&D funding levels within industry are seen to be insufficient. MOSST has emphasized that *"the mandate for innovation and resurged growth lies with the private sector. We cannot be subsidized into technological advancement. We must choose to invest in it so that we will remain internationally competitive."* In order for industry to increase its investments in innovation, a clear demonstration of the economic return and strategic value from such investments will be required. In a study conducted for MOSST, it was determined that the net return on investment from R&D in the oil and gas and mining industries during 1977 to 1981 was 31% compared to a rate of return of 21% for investments in physical capital.

3. **To maintain leadership in oil and gas technologies and expertise.** The oil and gas industry, like other commodity industries, is cyclical, with investment decisions frequently being taken for short-term results. Investments in R&D are also often made with a view to short-term results, i.e. less than 2 years. As a result, long-term developments suffer. Government, more insulated from these cycles, can provide a counter-balance and continuity in technology development during downturns.

4. **To enhance the role of government R&D programs in technology development and to improve the relevance and usefulness of government R&D programs.** The federal and provincial governments play a major role in oil and gas R&D. Periodically, independent evaluations of the programs are conducted and adjustments to the programs are made. As well, certain programs have industry input through advisory councils and through scientific program committees. One major assessment of all federal government R&D policies and programs, the Wright report, has been conducted. While these review mechanisms are essential, the recommendations are not always implemented. A result is the frequently heard comment by industry that studies, task forces and advisory bodies are "window-dressing".

   Successful innovation must meet technical and commercial objectives. As emphasized in the Wright report, the most effective research and development is that which is "demand-driven" rather than "supply-driven". Within government, technical objectives tend to be well defined. By comparison, commercial or market objectives are given much less emphasis. Government R&D could become more effective in maximizing the market's pull on the innovation process.

5. **To increase the role of universities in oil and gas R&D.** Universities form a reservoir of expertise in fundamental research that provides the basis for the development of new technologies. They also play a key role in supplying qualified personnel to industry and government. In the past, however, universities have been isolated from industry and government. The situation has improved in recent years through increased participation by universities in Alberta in oil sands research, and through the establishment of centres of excellence, such as those in Edmonton and St. John's, which work closely with the oil and gas industry and with government.

6. **To provide more opportunities for the performance of R&D.** Industry and government increase their R&D activity levels when given access to programs conducted by others. These co-operative projects would likely not have been conducted by individual firms or departments because of risk, funding or scale problems. Given the inherent uncertainties in R&D, increasing the number of "attempts" in arriving at solutions can lead to the eventual success of a research program.

7. **To improve the diffusion of technology.** A principal constraint on technology development and diffusion related to offshore oil and gas is the relative fragmentation and lack of coherence of efforts. In contrast, R&D in heavy oils and oil sands is better organized.

Options to Improve Technology Development

In view of these objectives, the following measures are suggested for consideration by MOSST, other departments, industry, universities, and research centres in the implementation of policies and programs aimed at promoting technology development. Both long-term and short-term measures are proposed.

1. Strategic Planning of Innovation

Successful innovation requires attaining both technical and market objectives. In the planning of R&D programs emphasis should be given to the flow of technology throughout the innovation process. Increased emphasis should be given to the eventual "destination" of the technology - the market. The suggested approach to the strategic planning of technology development consists of: identification of opportunities, mobilization of resources, attaining a better definition of the roles of R&D performers and funders, and development of a joint government-industry approach to long-term R&D planning.

As opportunities are numerous and resources are limited, a "niche" strategy to develop technology is proposed. Technologies identified would be considered according to various criteria, including: market opportunities, the strategic importance of the technology, existing and potential Canadian capabilities, and a risk/reward assessment of technology development.

While the limitations and uncertainties to long-term planning are recognized, these factors should not dissuade government and industry from better defining the opportunities from technological innovation, and the means of securing these opportunities under different development scenarios. With lower oil prices, a hiatus in oil and gas technology development could occur. In view of the continued need for developing new oil supplies, government should sustain its efforts in support of energy technologies. It is now an opportune time to "re-group", improve linkages, and continue active forward planning. Such an approach would counter past tendencies which have been described as "*when we are busy, there is no time; when things are slow, we have no money*". Without sustained efforts, Canada may at some future point in time require oil from the frontier, oil sands and heavy oil reservoirs on an urgent basis. Given the long-lead times in exploiting these resources, undesirable "crash" programs may have to be undertaken in response. It is also recognized that R&D efforts may require re-focussing and an extended time-frame for completion. These factors can be more clearly determined through use of explicit criteria that should be used for the evaluation of government R&D projects (see recommendation #3, following).

Canada has a leading edge in many oil and gas related technologies. To maintain this lead will require sustained efforts. Major areas requiring increased efforts in attaining Canadian capabilities or in realizing market opportunities for offshore oil and gas exist in information technologies, environmental protection technologies and natural gas management. For heavy oils and oil sands, strong domestic capabilities exist in most areas, while some improvements are possible in upgrading of bitumen and heavy oils, and innovative metering and control systems.

Attaining the objectives previously stated will require increased funding of innovation, by government and industry. Industry associations and government should encourage awareness within industry of the economic and strategic values of increased R&D expenditures. The present expenditure level of R&D, which is less than 1% of sales, should be reviewed by industry associations and individual firms, with the view of raising this level.

Joint planning of long-term R&D programs with associated funding commitments should be initiated for areas of national priority. A relevant model that could be examined for implementation of joint planning and funding is the Styrelsen for Teknisk Utveckling (STU) - the Swedish National Board for Technical Development. Another model, being developed by the Mining Association of Canada, is the Canadian Institute of Advanced Mineral and Metal Technology. This centre is a response to the perceived shortcomings in Canada's mineral R&D efforts which have been described as being fragmented, duplicative, poorly coordinated, inadequately funded and, in some cases, misdirected in focus. The mineral industry has identified technology as one of the few major factors with a strongly positive role to play in the future of the industry.

Similarly, a Canadian Oil and Gas Technology Institute could be established. The Institute, comprised of centres of excellence in industry, government, universities, and suppliers, would provide a national approach to identifying priorities and strategies for oil and gas R&D. One of the functions of a national institute could be the promotion of cooperative R&D programs.

2. Emphasizing Cooperative R&D: An "Open Architecture Approach"

The most effective means of promoting technology development and diffusion is through cooperative R&D.

A primary constraint on technology development and diffusion is the relative isolation of the oil and gas industry, the federal government, provincial governments, universities, research centres, and supplier and service companies. Existing organizations and R&D programs have been established to meet particular needs and operate within various contexts.

The focus should not be on reorganization of existing institutions performing R&D but improving their linkages. The aim should be towards greater coherence and understanding, of common purpose and consistent goals. Other benefits include shared risks and costs, increased levels of activities, attaining a critical mass in R&D, and continuity.

A principal method of increasing industry's commitment to R&D is by providing the opportunity to participate in joint ventures. Industry has shown an interest in participating in programs conducted by others. This has been evident from the growth of research centres that rely heavily on the direction and funding of industry, government and universities.

An "open architecture" approach to oil and gas R&D in Canada is proposed to overcome the relative isolation and improve the effectiveness and focus for technology development. Some methods to achieve this are:

- Promotion of joint R&D / technology development programs;

- Increased industry, university, and supplier access (support and participation) to government facilities and programs;

- Increased government access (support and participation) to industry, university, supplier facilities and programs;

- Increased delegation of new projects to those companies, technology centres or government laboratories identified as being most capable of performing them, with the aim of concentrating efforts and attaining the necessary "critical mass" at centres of excellence;

- Promotion of personnel exchanges on a term basis among industry, government, universities, research centres, suppliers and consultants;

- Encouragement of industry to have outside (e.g. government, university, research centres, suppliers) advisors on industry's research committees.

3. Improving Government R&D Programs

Management

To echo the recommendations of the the Wright Task Force and MOSST's Working Paper, a formal structure for monitoring and directing the performance and relevance of federal R&D programs is essential. For each federal government program, careful consideration should be given to the role of non-government advisors or directors.

One option is the establishment of a Board of Directors for each government R&D program. The Board, comprised of individuals from both within and from outside government having expertise in oil and gas related R&D, would establish and define objectives, set priorities, monitor performance, and provide technical advice. Industry frequently makes use of outside directors; this practice should be emulated by government.

In other cases advisory committees, if used effectively, can perform these functions. The National Research Council's Associate and Advisory Committees are examples of such a mechanism.

Funding
Ideally, government could determine the "optimal" level of funding for oil and gas related R&D. In view of the objectives to maximize opportunities, maintain leadership and develop nascent Canadian capabilities in oil and gas technologies, and considering the magnitude of oil and gas projects and possible government revenues, federal government funding of oil and gas R&D appears to be barely adequate. In recent years the trend in federal funding for energy R&D as a whole has been down, and oil and gas funding has been eroded. In the present cost-reduction environment within government, increased R&D funding, and continuation of certain existing programs (i.e. AMTR&D) is difficult to secure. A clear demonstration of the returns (benefits) from government sponsored projects will be required before increased funding can be expected. While government should increasingly view funding of innovation as an investment with tangible returns, it is apparent that this approach is not widely adopted or used as a justification for seeking new funding.

Explicit criteria for evaluating government R&D projects should be encouraged, and may include:

- the degree to which a project satisfies departmental responsibilities,
- the degree of industry advantage through productivity gains and cost reductions,
- the market potential for the technology in terms of demand growth and export potential,
- the technical feasibility, and the magnitude of change required in developing the technology,
- the risks and rewards (e.g. ROI) from a project,
- the availability of the technology from foreign sources versus Canadian capability,
- the applicability of technologies to other industries,
- identification of limiting factors,
- the timing of technology needs,
- the social and private returns from R&D,
- market assessment of new technologies identified that should be developed in Canada,
- selection of priority technologies that should be developed in Canada.

A portfolio approach to well-defined R&D areas would allow balancing of short and long-term objectives and associated risks.

The funding cycles of departments and the UP program are often lengthy. Government departments should investigate the possibility of allocating discretionary funds for application to urgent or timely opportunities as they arise.

4. Improvements to Industry Support Programs

Canada provides generous incentives to R&D and technology development, but reviews of government policies and programs have identified several areas where improvements can be made. The author frequently heard widespread support within industry for the conclusions and recommendations of the Wright report, yet there was concern that the recommendations were not being implemented. The following measures are proposed to address the various issues of government R&D activities:

- Preparation of a federal response to the Wright Task Force and a progress report on measures that have been implemented;

- Increase industry's awareness of government programs;

- As programs tend to be reactive, there is a need for new pro-active approaches in supplier development to ensure that competitive Canadian companies are well positioned to compete in domestic and international markets. One intangible yet real problem in developing domestic technology is the widespread lack of confidence and risk-taking by Canadians.

- Regional delivery systems should be encouraged along with the establishment of a single window approach to government programs;

- Government managers should be explicitly encouraged to take a market-oriented and entrepreneurial approach in delivery of programs. Certain managers have successfully taken this role as a personal initiative.

- The number and requirements of support programs are cumbersome, making them difficult to access. A "buddy system" could be developed where one government officer can assist and guide an applicant through various programs.

- Problems may arise in the NSERC matching funds arrangement with industry. NSERC should ensure that industry and universities are fully aware of the criteria applied by NSERC in these funding arrangements.

- Methods should be examined of ways to further increase industry funding of universities, possibly through tax measures.

5. Addressing Information Access, Dissemination and Confidentiality Policies

Although a number of government programs are generating valuable results, they tend to have a very low profile; consequently, technology diffusion is limited. Adequate resources should be allocated at project inception to "networking" and other dissemination methods such as the timely release of publications, notifications, presentations and the like.

No clear and consistent policy exists concerning the confidentiality of the results of government-funded R&D. This is in part due to the difficulty in balancing two objectives: the need for widespread dissemination to Canadian firms, while protecting this information from foreign companies. In general, preference should be given to maximizing access to results rather than keeping results secret. Participation in projects is seen as one method of helping Canadian firms gain maximum advantage in government-funded R&D projects.

6. Utilization of the Approvals Process

In some countries, the regulatory approvals process for oil and gas projects is used to encourage the development of domestically produced technologies. Canada has the regulatory framework for achieving this aim, but technology-intensive products and services tend to get "lost in the noise." Rather, emphasis is given to matching existing suppliers of conventional and existing technologies with industry, based on projected demand. Measures that could encourage the profile of technology-intensive products and services include:

- R&D and new technology requirements could be identified in support of applications to FEARO.
- Greater emphasis on R&D could be given within the COGLA approvals process, e.g. in technology agreements and "goodwill" agreements, as part of Canada Benefits plans within Exploration Agreements or in production or transportation approvals. A cooperative approach rather than that of mandatory directives is strongly encouraged. A code of good conduct that includes R&D performance would be an appropriate vehicle.
- Closer ties between the oil and gas industry (through the Canadian Petroleum Association or the Canadian Market Opportunities Program), technology-intensive companies (through the Canadian Advanced Technology Association and Oceanic Canada), and government (COGLA, DRIE) should be encouraged.
- CMOP and DRIE should play an important role in identifying market opportunities for technology-intensive products and

services, and should identify these areas explicitly.

- As regulations are reviewed, emphasis should be on ensuring that performance rather than design requirements are in place. The adoption of "best available technology" policies, particularly where safety is concerned, should be encouraged.

- Increased recognition should be given to the importance of large domestic and international markets to the economic viability of technologies. Regional preference guidelines tend to prevent companies in other provinces from sharing in the benefits of oil and gas projects. In some cases, the guidelines may lead to duplicated efforts in technology development.

7. Enhancement of Export Policy Measures

Open foreign markets are crucial for the development of Canadian technologies and for the adoption of foreign technologies. There is, however, an ingrained attitude that Canadian firms cannot manufacture equipment because of the small domestic market. Small countries, such as Sweden, have disproved this by gaining access to world markets. Some Canadian companies have entered these markets, but major opportunities remain. A "unite and conquer" approach among Canadian companies should be encouraged. An improved market intelligence system with regional delivery should be a priority of government. Some countries, such as Norway, attempt to deny foreign firms from gaining access to domestic markets. Overcoming these hurdles requires measures including:

- trade liberalization,
- bilateral and multilateral technology agreements with various countries,
- adoption of a niche strategy - Canada cannot and should not develop all oil and gas technologies, but can excel in some areas,
- negotiation of joint ventures and phasing out of foreign technologies where applicable,
- pursuit of world product mandates for certain technologies,
- establishment of Canadian trading companies and consortia.

8. Strengthening Contracting-Out & Commercialisation Policies

The contracting-out and commercialisation policies are effective ways of promoting technology development and transfer. The PERD program, for example, has been very successful in providing opportunities for industrial innovation: in recent years, some 70% of PERD expenditures were contracted out.

Where possible, the application of these policies should be strengthened. Government should ensure that adequate resources (funding, person-years and expertise) and leeway within the bureaucracy are provided to project managers to intensify these efforts.

9. Development of Northern S&T and Ocean S&T Strategies

Northern and Ocean science and technology activities could benefit from improved coherence through longer-term strategies and supporting policies. The National Science and Technology Policy being developed by MOSST should be regionally responsive by considering the particular needs associated with northern and ocean S&T policies. The U.S. *Arctic Research and Policy Act* of 1984 provides one example of how government can stimulate and coordinate a national research program. Certain features of this approach could be adopted in Canada.

Northern and oceans S&T strategies should be broadly based and address the role and potential applications of science and technology. Elements of these strategies should be directed to topics such as:

-Non-renewable resource development,
-Renewable resource development,
-Government infrastructure,
-Long-term fundamental research,
-Resident scientific and technical community,
-Sovereignty and defence, and
-International scientific relations.

* * *

-APPENDIX A-
PRINCIPAL CONTACTS

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Bryan Cook, Office of Energy Research and Development, Department of Energy, Mines and Resources, Ottawa

George Davies, Canada Oil and Gas Lands Administration, Ottawa

Glenn Davis, Canadian Marine Drilling Ltd., Calgary

Jan De Jong, Husky Oil Ltd.

Ian Denness, Gulf Canada Resources Inc.

Jacques Denoit, Mobil Oil Canada Limited, St. John's

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-APPENDIX B-
NOTES & SOURCES

Additional notes and principal sources are contained in this Appendix. More complete citations are provided in Appendix C.

1. OVERVIEW OF THE OIL AND GAS INDUSTRY

Summary and Outlook

Recent statements of suggested energy policies include: Senate of Canada, *Canadian Energy Policy - An Interim Report*, and Richard G. Harris, *Trade, Industrial Policy and International Competition.*

Future world oil prices are discussed in: P.C. Des Prairies, X. Boy de la Tour, J.J. Lacour, "Progressive Mobilization of Oil Resources: A Factor in Ensuring Moderate Price Rises", parts 1 and 2, *Energy Policy,* and W. Goldstern, "Price and Prospects for Oil: Carrying the Burden of Excess Capacity in the 1980s and Beyond", *Energy Policy.*

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Oilweek, March 10, 1986.

Statistics Canada, Catalogue 72-002, August 1985.

R&D and Financial Performance

U.K. Ranga Chand and Susan D. Simeon, *Research and Development in the Canadian Corporate Sector.*

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Financial Performance

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Canadian and Foreign Ownership

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Petroleum Monitoring Agency, *Monitoring Survey 1984.*

The purchase of Gulf Canada by Canadian sources in 1985 had a significant impact on the figures indicated, raising Canadian ownership based on upstream revenues to 47% from 42%.

Size and Ownership
Based on Financial Post, *Survey of Mines and Energy 1985.*

Exploration Activities
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Production Activities
Petroleum Monitoring Agency, *Monitoring Survey 1984.*

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Oilweek, June 17, 1985.

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Trade Balance
Economic Council of Canada, *Connections - An Energy Strategy for the Future* (based on data from Statistics Canada and the CANDIDE model); data for 1984 from Statistics Canada catalogue no. 65-202 and 65-203, 1984. Totals include radioactive ores.

R&D Activities
Amounts in contract R&D figures include some non-energy expenditures. For instance, in 1984, non-energy expenditures amounted to some 32% of contract R&D spending abroad.
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CHAPTER 2. TRENDS FOR THE OIL AND GAS INDUSTRY

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Economic Council of Canada, *Connections - An Energy Strategy for the Future*, Table 4-4, p.33.

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Actual 1985 figures are from *Oilweek*, July 22, 1985. Where **forecasts** citing 1985 data are used, NEB data from 1983 are used for consistency in forecasts.

R.M. Procter et al, *Oil and Natural Gas Resources of Canada 1983.*

Canada Oil and Gas Lands Administration, *Annual Report 1984.*

CHAPTER 3. GOVERNMENT POLICIES AND PROGRAMS

Federal Policies and Programs

The 300 policies and programs have been identified in Hardy Associates (1978) Ltd., *A Technology-based Industry and the Canadian Government - Offshore Oil and Gas: a Case Study.*

The *Intergovernmental Position Paper on the Principles and Framework for Regional Economic Development* issued in June 1985 consists of an agreement among the federal government and all ten provinces and two territories. The principles of the agreement emphasize the need for regional economic development that will improve employment and income within the regions, particularly in the less developed regions. A regional economic development action plan includes the continued use of Economic and Regional Development Agreements (ERDAs) to deliver regional development program, harmonization of financial support programs, and discussion of regional development goals.

Frontier Energy Policy

Energy, Mines and Resources Canada, *Canada's Energy Frontiers - A Framework for Investment and Jobs.*

See also Robert B. Parsons, "A New Regime for the Frontier", the *Journal of Canadian Petroleum Technology.*

Atlantic Accord

The Atlantic Accord - Memorandum of agreement between the Government of Canada and the Government of Newfoundland and Labrador on offshore oil and gas resource management and revenue sharing, Feb. 11, 1985.

Decisions made by the federal government are those related to Canadianization policy; those made under legislation not specifically related to oil and gas activities and under federal jurisdiction; and decisions related to application of federal taxes. Decisions made by the Newfoundland Government focus on matters pertaining to the royalty regime and in areas related to provincial laws. The Board makes all other decisions relevant to the regulation of offshore petroleum-related activities. These include the declaration of discoveries, granting of production licenses, compliance functions, administration of regulations respecting "good oilfield practice", and the exercise of emergency powers. The Board also makes what are called "fundamental decisions" although these decisions must be considered by both governments before being considered final. Fundamental decisions are those that affect the pace and mode of exploration and pace of production, in particular rights issuance, extraordinary powers and approval of development plans. Provisions are in force to resolve disagreements between the governments on fundamental issues. The Federal Minister is responsible for approving a fundamental decision until national self-sufficiency and security of supply are reached. The Provincial Minister will be responsible for approving fundamental decisions affecting the mode of development unless this unreasonably delays the attainment of self-sufficiency and security of supply. Security of supply is defined as the anticipated national requirements for hydrocarbons over the next five years.

Canada-Newfoundland Ocean Industry Sub-Agreement

Canada/Newfoundland Ocean Industry Development Subsidiary Agreement, August 16th, 1984.

Projects under the Agreement are administered by a Management Committee on behalf of federal and provincial ministers. Total program funding amounts to $28 million and is shared by the federal government ($19 million) and the province ($9 million). Six grant programs are provided under the agreement: ocean industry assistance; marketing/product enhancement; business & community development; opportunity identification/project assessment & evaluation; promotional services; and innovation and productivity support.

Funds are made available for the federal Ocean Industry Development Centre (OIDC) and support for the provincial office for coordination and administration. The OIDC is responsible for the promotion and delivery of federal programs and also for other activities such as encouragement of joint ventures. It is also the focal point for federal cooperation with industry and the province. The provincial office, while coordinating its activities with OIDC, is responsible for delivery of provincial support programs.

Canada-Nova Scotia Sub-Agreement

Canada-Nova Scotia Subsidiary Agreement on Ocean Industry Development, July 24, 1981.

The Agreement has a term of five years, and expires in July 1986. Funds available under the Agreement amount to $35 million, comprised of $22,950,000 from the federal government and $12,050,000 from the province. Federal programs under the Agreement include: creation of an Ocean Industry Development Office (OIDO), capital assistance, market assistance, funds for an incubator mall, the Ocean Industrial Park, applied research support, and assistance to an ocean industry trade association in Nova Scotia.

The OIDO, operated by DRIE, administers the Capital Assistance Program, Marketing Assistance Program, and the Applied Research Program. The Capital Assistance Program is designed to assist new and existing ocean industries in Nova Scotia, the Marketing Assistance Program to maximize development of goods and services, the Applied Research Support Program to assist with the acquisition 'of sophisticated product and technologies equipment, facilities and technology.

Provincial projects include municipal taxation assistance, expansion of an Ocean Industrial Park, and establishment of the innovation centre for the ocean industry. The Ocean Industries Innovation Centre provides assistance to small businesses in the form of advice, problem solving and financial support.

The Education and Training and Research and Development funds were to be financed by a levy on operators in the offshore regions.

The National Energy Program

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G.B. Doern and G. Toner, *The Politics of Energy.*

G.C. Watkins and M.A. Walker (editors), *Reaction: The National Energy Program.*

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Canada's Oceans Policy

Discussion of the Policy and subsequent implementation is contained within *Canada's Oceans Policy,* A.E. Collin (chairman).

Chapter 4. TECHNOLOGICAL SUPPORT FOR THE OIL AND GAS INDUSTRY

Government Oil & Gas R&D Expenditures

International Energy Agency, *Energy Research, Development and Demonstration in the IEA Countries.*

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Energy, Mines and Resources, *Energy R&D Resources.*

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Market Potential for New Technologies

Sub-Committee on High Technology, *Lost in the Noise - A report to the Major Projects Task Force.*

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Note: DRIE has not included Beaufort Sea production before 1995. While forecasts of activity levels for the Beaufort are speculative, some development and production activities are anticipated before 1995. If it were assumed that 2 islands were constructed and transportation systems in place, at $3.7 billion per development, an additional $7.4 billion could be added to the DRIE figures, bringing the total to approximately $23.8 billion. Figures for Beaufort Sea development are from Eglington and Uffelmann, *An Economic Analysis of Hydrocarbon Developments in the Beaufort Sea.* According to other sources, fields that might be developed are Amauligak, Tarsiut, Issungnak, Nipterk, and Igalak.

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Swan Wooster Engineering Co. Ltd., *Alaska Oil & Gas Drilling and Production Equipment, Services and Technology Opportunities.*

Swan Wooster Engineering Co. Ltd. and Tri-Ocean Engineering Ltd., *Opportunities in Offshore Drilling Equipment and Technology in Southern California.*

CHAPTER 5: TECHNOLOGICAL REQUIREMENTS

A. Offshore Oil and Gas

Most of the material on offshore technologies in this chapter was derived from interviews and the references in Appendix C. Some selected references include those listed following.

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A perspective on general trends in ocean information systems can be found in G. Holland, *Planning for the 90's: DFO's Oceans Needs in Information Sources, Services and Systems.* and in S.B. MacPhee, *The Impact of New Technology on Ocean Science and Surveying - 1995*, 1985.

Examples of databases are:

- Canadian Sea Ice Information System, C-CORE, which compiles, integrates, abstracts and synthesizes data from hundreds of studies.
- Ice Data Base, Atmospheric Environment Service
- Marine Statistics System (MAST), Department of Fisheries and Oceans
- Wave climate data base, Department of Fisheries and Oceans
- Marine Environmental Database (MEDS), Department of Fisheries and Oceans
- Models for wave hindcasting, ocean current hindcasting, current meter, current surges, wave forces on offshore moored platforms,
- Hydrographic databases (AES, DFO, CHS)
- Computerized database of Arctic marine environment (Arctec Canada Limited)

Bibliographic information is also provided by the AINA's Arctic Science and Technology Information System (ASTIS) and C-CORE's oceans engineering database.

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Nordicity Group Ltd., *Technology for Canada's Oceans.*

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B. Heavy Oils and Oil Sands

Bitumen: A naturally-occurring viscous mixture of hydrocarbons that may contain sulphur compounds and that, in its natural state, is not recoverable commercially through a well.

Heavy oil: A high-viscosity, heavy-gravity hydrocarbon.

Synthetic Crude: A semi-refined hydrocarbon, usually derived from bitumen, used as feedstock in conventional oil refineries.

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"Petroleum Transportation by Pipeline", Winter 1982/83
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-APPENDIX D-
ACRONYMS

ACV	Air-cushioned vehicle
AINA	Arctic Institute of North America
AMTR&D	Arctic Marine Transportation R&D Program
AOSTRA	Alberta Oil Sands Technology & Research Authority
APOA	Arctic Petroleum Operators' Association
ARC	Alberta Research Council
CANMAR	Canadian Marine Drilling Ltd.
CANMET	Canada Centre for Mineral and Energy Technology
C-CORE	Centre for Cold Ocean Resources Engineering
CCRS	Canada Centre for Remote Sensing
CEIC	Canada Employment and Immigration Commission
C-FER	Centre for Frontier Engineering Research
CMOP	Canadian Market Opportunities Program
COGLA	Canada Oil and Gas Lands Administration
COOSRA	Canadian Offshore Oil Spill Research Association
CPA-OOD	Canadian Petroleum Association - Offshore Operators Division
CSA	Canadian Standards Association
DFO	Department of Fisheries and Oceans
DRIE	Department of Regional Industrial Expansion
EARP	Environmental Assessment Review Process
ECC	Economic Council of Canada
EMR	Energy, Mines and Resources (Dept. of)
EOR	Enhanced oil recovery
ERDA	Economic and Regional Development Agreements
ESRF	Environmental Studies Revolving Funds
FEARO	Federal Environmental Assessment Review Office
GNWT	Government of the Northwest Territories
IEA	International Energy Agency
LNG	Liquefied natural gas
LPG	Liquid petroleum gas
MOSST	Ministry of State for Science and Technology
NEB	National Energy Board
NEP	National Energy Program
NGL	Natural gas liquids
NOIA	Newfoundland Ocean Industries Association
NORDCO	Newfoundland Oceans Research and Development Corp.
NRC	National Research Council
NSERC	Natural Sciences and Engineering Research Council
NSRF	Nova Scotia Research Foundation
OECD	Organization for Economic Cooperation and Development
OERD	Office of Energy R&D
OIDC	Ocean Industry Development Centre
OIDO	Ocean Industry Development Office
OPEC	Organization of Petroleum Exporting Countries
PERD	Panel on Energy Research and Development
PGRT	Petroleum and Gas Revenue Tax

PIP	Petroleum Incentives Program
PMA	Petroleum Monitoring Agency
R&D	Research and development
RD&D	Research, development and demonstration
ROI	Return on investment
ROV	Remotely operated vehicle
SAR	Synthetic aperture radar
SLAR	Side-looking airborne radar
SRC	Saskatchewan Research Council
SSDC	Semi-Submersible Drilling Caisson
S&T	Science and Technology
UP	Unsolicited Proposals Program