**INNOVATION AND PERFORMANCE: THE CASE OF
THE UPSTREAM PETROLEUM SECTOR**

PhD Thesis

By

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Bachelor of Arts (Economics), Master of Arts (Economics),

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The responsibility for errors and omissions rests with the author.

Jai Persaud

ABSTRACT

This thesis investigates innovation in the upstream crude oil and natural gas sector, a strategic part of the Canadian economy and a vital industry for North American energy trade and security. Significant interest exists in understanding innovation in this sector from a private and public policy perspective. Interest in the sector has intensified recently due to concerns about world oil supply, Canada's oil sands development, and the potential that Canada may become an "energy superpower." The study examines the factors that drive companies involved in exploration, development, and production in the upstream petroleum sector to innovate and the impact of their innovation activities through major technologies on their performance. The thesis focuses on process innovation, which involves the adoption of new or significantly improved production processes, and is distinct from product innovation, which is based on the development and commercialization of a product with improved product characteristics to deliver new services to the consumer.

The thesis provides a comprehensive review of the literature and develops an investigative model framework to examine the drivers of innovation and the impact of innovation on performance in the upstream petroleum sector. The research employs a survey questionnaire that was developed to obtain data and information, which was missing in the literature or not publicly available to test key relationships of innovation and performance indicators. In addition to the survey questionnaire, a number of knowledgeable experts in the industry were also interviewed. A total of 68 respondents completed the survey questionnaire, accounting

for 40 percent of the firms in the industry. This percentage goes up to over 50 percent when account is taken of extremely small firms who could not fill out the survey. Further, the 68 respondents account for most of the industry revenues, production, and employment. The respondents include most of the key explorers, developers, and producers as well as the owners of the major projects and oil sands developments. Almost all firms in the industry with revenues above \$1B with employees above 1000 responded to the survey. As well, many companies have joint project arrangements and farm-in agreements with other companies in the industry. Hence, this survey is considered highly representative of the industry. Industry associations were very helpful in providing advice, and in endorsing the circulation of the questionnaire. The use of the telephone was the most effective in soliciting responses to the questionnaire. About 80 percent of the respondents expressed an interest in obtaining a copy of the results of this study.

The results show that the sector relies more heavily on acquiring advanced machinery and equipment, processes and other external knowledge than on internal R&D. Advanced machinery and equipment includes embedded R&D. 3D and 4D seismic stand out as the most relied upon in exploration, horizontal wells in development activities, and field recovery in production. Increasing productive capacity, reducing costs and reducing environmental impact are the three main drivers of innovation. Collaboration is important to the sector and agreements with competitors and suppliers are ranked as most important. The main reason for collaboration is to gain access to external knowledge. Government tax incentives (e.g., the Scientific Research and Experimental Development) (SR&ED) tax credit

and its fiscal framework are important in spurring R&D. Fiscal policies, on the other hand, are more important for acquiring advanced machinery and equipment, advanced processes, and other external knowledge.

The study has several broad implications with respect to the application of technologies:

- Without the adoption of major technologies, costs would have been substantially higher and productive capacity and productivity much lower. This study also contributes to the view that resources should not be treated as a fixed stock but as flow which can be improved.
- The environment is an important driver of innovation, particularly environmental regulation. Providing the right mix of regulation and leaving firms to undertake innovation may result in favorable impacts.
- Increasing R&D tax incentives may not necessarily have an increased direct impact on innovation in exploration, development, and production compared to other types of firms in the economy. The innovation impact, however, may be increased indirectly through the acquisition of imbedded R&D.

- Collaboration among firms and with government can be useful to address specific industry problems. Government's role will continue to be important in developing pre-competitive technologies for achieving public policy goals.
- Technology can play an important role in Canada becoming an "energy superpower" and, more importantly, a "clean energy superpower" and contributing to energy security in Canada and in the U.S.

Discussions with industry officials suggest that water availability, energy availability for oil sands development, skill shortages, and super depletion allowances for CO₂ sequestration are important issues and challenges for the industry. These areas warrant investigation. In addition to these issues, this thesis concludes by making suggestions for further research, including international comparisons with respect to innovation, tax incentives and R&D, Canada's future ability to influence oil prices through technological breakthroughs, specific technologies which involved government and industry cooperation, and alternate sources such as nuclear to meet growing energy requirements. It is expected that this thesis will contribute to the literature in several ways, including how innovation takes place in the upstream sector, the influence of key technologies, the role of collaboration, and the impact of government policies. Lesser emphasis on R&D should not be considered as being non-innovative. The acquisition of advanced machinery and equipment, advanced processes, and other external knowledge include embedded R&D. The findings of this study may help to dispel the myth that the natural resources sector is a "low tech" sunset industry. Although

the thesis is highly representative of the industry, one should be careful in generalizing the findings of the study to other sectors of the economy.

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Innovation and, more particularly, technological innovation, has long been acknowledged as one of the critical driving forces for improving profitability, competitive position, and the longevity and survival of the firm (Schumpeter, 1939; Porter, 1985a; Hamel and Prahalad, 1994; Guan, *et al.*, 2005). Baldwin, *et al.*, (1995a) note that adoption of new technologies is a key element of a firm's success. Arvanitis and Hollenstein (2001, p. 378) note "Rather than the generation of new technology it is its diffusion throughout the economy which affects productivity growth at the macro level." Mitropoulos and Tatum (2000) make a similar point noting that benefits from technological advances depend on the extent to which these technologies are utilized.

Innovation by firms leads to improvement in the welfare of society. Innovation and improved productivity lead to improvement in economic performance (Solow, 1988; Gu and Tang, 2004). *The Global Competitiveness Report: 2006-2007* (World Economic Forum (WEF), 2007) notes that "Raising productivity – i.e., making better use of available factors and resources – is the driving force behind the rates of return on investment which in turn determine aggregate growth rates of an economy." From a public policy perspective, interest in innovation stems from perceived benefits such as job creation, increase in productivity, higher economic growth, international competitiveness, a better standard of living and well-being, and improved environmental and social well being. Technological innovation is viewed as a key factor for reducing Canada's productivity gap relative to the United States,

its largest trading partner (Sharpe, 2005; Nicholson, 2003). Recognizing the importance of innovation, the Government of Canada has also made significant commitments in recent federal budgets toward improving Canada's innovation performance. Moreover, the Government is interested in making Canada one of the most innovative countries in the world, as is reflected in Canada's *Innovation Strategy* (Industry Canada, 2002) and several *Throne Speeches* (2002, 2003, 2004). In announcing its new Science and Technology strategy, the Prime Minister of Canada (May 17th 2007) noted that: "In today's world, scientific and technological innovation is fundamental to economic and social progress." In spite of the importance of innovation, our understanding of innovation is limited (Porter and Van der Linde, 1995; OECD, 2003a; Harris, 2005). Innovation is complex and involves a continuous process of discovering, learning, and applying new technologies and techniques from numerous sources. Measuring innovation and its impact can be a significant challenge and further, there is a paucity of literature on technological innovation in the upstream petroleum sector.

Significant interest exists in understanding innovation in the Canadian resource sector. This thesis investigates innovation in the upstream crude oil and natural gas industry, a strategic sector of the Canadian economy and a vital industry for North American energy security. Interest in the sector has intensified during the work on this thesis, in part due to concerns about world oil supply, Canada's oil sands development, and the potential that Canada could become an "energy superpower" and a "clean energy superpower." The study examines the drivers of innovation of companies that are involved in exploration, development, and production of petroleum and natural gas and also of the impact of their innovation activities

on their performance. The thesis focuses on process innovation that involves the adoption of new or significantly improved production processes, as distinct from product innovation, which involves the development and commercialization of a product with improved product characteristics to deliver new services to the consumer.

The upstream petroleum sector involves exploration for and development and production but not refining of oil and natural gas. Throughout this document, the terms “oil and natural gas sector” and “upstream petroleum” will be used to refer to the same sector.¹ Exploration and development of crude oil and natural gas face several risks including geological, technical, price, fiscal policy, and political uncertainty (Conaway, 1999; Holmes, *et al.*, 2006). The upstream petroleum sector is a major part of Canada’s energy and resources sector and of Canada’s economy; it operates in a highly competitive global economy in which oil prices are determined internationally and natural gas prices determined within the North American context. Oil is a key source of primary energy in Canada and around the world. Oil trade is truly an international business and oil is the single largest item of international trade whether measured by volume or value.

Over the past century, there has been a growing role for oil and natural gas in fueling development around the globe and many studies on energy futures tell us that oil and gas will remain dominant in world energy supply well into this century according to the International Energy Agency (IEA) (IEA, 2005). According to the IEA (2006a), oil will remain the most

¹ The downstream sector is involved in refining, distributing and marketing of crude oil, natural gas and other petroleum products. The thesis does not look at the application of technology in the downstream petroleum sector which has a long history of using modern technologies and as a result its impact is better understood.

heavily traded fuel in 2030 but natural gas trade will also grow rapidly. The upstream petroleum sector is strategic to both Canada and the United States. Both countries have similar energy cultures with substantial dependence on oil and natural gas. The U.S. and Canada meet over two thirds of their energy requirements with oil and gas (U.S. DOE/EIA, 2007b; NEB, 2006a). Canada exports a significant amount of its oil and natural gas production to the U.S. There are great similarities between the upstream sectors in both countries. Canada is both a net oil and gas exporter, and it plays a key role in contributing to energy security at home and to that of the U.S. and other OECD countries.

Canada's upstream sector is unique in the world in terms of the various sources of oil and gas supplies; these include conventional light and heavy oil, oil sands, and frontier supplies produced mainly from large projects (e.g., Suncor, Syncrude, Hibernia and Terra Nova). An analysis of recent production data of the National Energy Board (NEB) and the Canadian Association of Petroleum Producers shows that major projects account for an increasingly larger share of Canada's oil supply. A substantial share of Canada's production is heavy oil, which it cannot use and must export. Both the U.S. and Canada are considered the most drilled territories in the world and relatively high cost producers. The sector faces significant challenges to reduce costs in the face of depleting conventional reserves, to tap higher-cost sources of supply from Canada's frontier (offshore and northern) and oil sands (very heavy oil), and, at the same time, to meet more stringent environmental and sustainable development constraints. In an increasingly global economy, firms have to be highly innovative to retain and gain a competitive advantage.

This thesis will provide valuable information and insights into innovation in the upstream oil and gas sector and contribute to an understanding of Canada's innovation system.

The thesis will also provide useful information that adds to our understanding of analysing technology with respect to oil and gas supply, forecasting, financial assessments, reserves and resources base, and energy security. The development of innovation policy requires a detailed understanding of the innovation process. Studies on innovation should yield insights into: the impacts of innovation, collaboration, obstacles, and the role of government policies, and into the way these government policies are perceived by businesses.

1.2 Innovation Context

Utterback (1974) maintains that a firms' potential for innovation is a function of its environment which includes economic, social, and political factors. With particular reference to the natural resources sector, Bohi (1999) maintains that discussion of technological innovation cannot be complete without considering the environment into which innovations were introduced. Similarly, Teece (1986) and Holbrook and Hughes (2002) note that innovation occurs within a competitive environment and firms should not be considered in isolation from the competitive environment in which those firms exist. It's all about context, according to Tornatzky and Fleischer (1990).

Baldwin (1997a) argues that significant focus has been on the so-called "high tech" and "low tech" firms and this categorization obscures the level of innovativeness of certain industries.

Sometimes, the resources sectors are portrayed as being “low-tech,” sunset, and polluting industries. Unstable results from innovation adoption and diffusion models call into question the validity and generalizability of innovation studies (Downs and Mohr, 1976). The *new economy* suggests an economy that is knowledge based, technologically advanced, and international in nature (Doern and Gattinger, 2002).

The upstream petroleum industry is a major part of Canada’s resource sector and a strategic component of Canada’s economy. According to the Report of the House Standing Committee on Industry (2000), the upstream oil and gas sector is a key driver of Canada’s economy (particularly Alberta’s). Oil sands production is expected to be Canada’s largest natural resource development opportunity over the next decade (Industry Canada, 2001). The prominence of oil sands development has increased even more since then and Canada has been viewed recently as becoming an “energy superpower.”² Canada’s upstream oil and natural gas sector operates in a competitive national and international environment and must, therefore, compete for investment dollars with other sectors (e.g., information and communication technologies) within Canada and internationally. In Canada and around the world, business confidence is also supported by a stable and competitive business environment that encourages investment in the sector and promotes sustainable development and wise use of resources.

² The Prime Minister of Canada used this term in his speech at the Economic Club in New York, September 20th, 2006; see also the Conference Board of Canada 2007.

Several industry associations responded positively to this study. The Canadian Association of Petroleum Producers indicated that they were interested in the results and asked the members of a newly formed Innovation Committee to support the research. Dr. Murray Stewart of the Energy Council also circulated the questionnaire to his membership with a covering letter of his own. He also sent the letter to his counterparts. Officials at NRCan expressed significant interest in the study from the standpoint of better understanding innovation in the sector as well as for the long term implications for oil and gas supply and government policies. NRCan has substantial strengths in the sciences and technology applications related to natural resources and, in particular, mining and energy (Council of Canadian Academies, 2006).

The application of advanced technology (e.g., three dimensional (3D) and four dimensional (4D) seismic technology and horizontal wells) is relatively new and there is a paucity of literature on innovation. The common view is that unless technology improves to make it easier to find and develop the next generation of resources, the average cost of production will inevitably rise over time. The pressure to lower costs also underscores the need to undertake the development and application of technologies in the sector. Emerson (1997) notes that investment will take place as long as prices exceed costs. Both Canada and the United States are price takers of oil (oil prices are determined by international markets with major producers in the Persian Gulf exercising strong influence on prices). If oil cannot be produced at home at less than the prevailing market prices, it can be imported into both countries from other producing nations. Governments have a strong interest in competitiveness because companies will relocate to lower cost-producing regions.

There is a major emphasis on energy security among members of the IEA, particularly the United States, Japan, and Europe (IEA, 2003). Europe is increasingly concerned about dependence on Russian natural gas. The concern of energy security in the U.S. has heightened since the terrorist attacks of September 11, 2001.³ In addition, the rapid growth of energy demand in major developing countries, in particular, China and India, is also cause for concern for long term petroleum supply. India and China have accounted for most of the growth in petroleum demand in the last several years (Fesharaki and Sueda, 2004). The IEA (2003) notes that energy security continued to be a key concern of policy makers in 2003, influenced by the current concerns in oil markets. Oil prices remain a key variable to determine the health of economies and the rapid increase in prices over recent years has been driven largely by geopolitics and concerns about security of supply. Energy security has long focussed on assurance of sufficient crude oil availability (Economist (April 30th- May 6th. issue, 2005). The development and production of domestic oil and gas resources are seen as key factors for ensuring secure, reasonably priced sources of energy.⁴

The sector faces significant challenges to reduce costs in the face of depleting conventional reserves, to tap higher-cost sources of supply from Canada's frontier (offshore and northern)

³ The U.S. places a strong emphasis on energy security. The development of oil and gas and of other sources of energy, and the diversification of import sources and investment in energy efficiency figure prominently in U.S. energy policy.

⁴ Renewable sources of energy, diversification of import sources and investment in energy efficiency, and providing an appropriate regulatory environment are also seen as important for improving energy security (see for example, U.S.-EU Summit – (<http://www.whitehouse.gov/infocus/eusummit/2007/>)).

and oil sands (very heavy oil), and, at the same time, to meet more stringent environmental and sustainable development constraints. In an increasingly global economy, firms have to be highly innovative to retain and gain a competitive advantage. The application of advanced technologies in the petroleum sector is fairly recent. This is partly due to the fact that oil and gas resources were relatively easy to find and develop. As well, technological breakthroughs have occurred only in recent years. There is, moreover, a paucity of literature on technological innovation in this sector. It is expected that this thesis will provide valuable information on, and insight into, innovation in the upstream oil and gas sector, and will contribute to an understanding of Canada's innovation system.

The production and use of oil, natural gas, and other hydrocarbons have significant impact on the natural environment and the atmosphere. The overall performance and global competitiveness of the resource sectors have major consequences for other sectors of the economy including manufacturing, transportation, buildings and infrastructure, health, marine, and finance and other services. Increasingly innovation is seen as the means to achieve sustainable development objectives.

1.3 Innovation Surveys

Innovation surveys are relatively new and evolutionary. They are, however, useful for understanding innovation (Baldwin and Hanel, 2003). Following the guidelines set out in the *Oslo Manual* (OECD, 1997), innovation surveys in the last few years have contributed significantly to a more comprehensive picture of the nature of innovation activities in

manufacturing within a wider exercise of developing and refining science and technology indicators and understanding the technological performance of firms (Sirrili, 1997; Sirilli and Evangelista, 1998).

Table 1.1

Surveys on Innovation Conducted by Statistics Canada

The Survey of Innovation and Advanced Technology 1993 — surveyed manufacturing firms.

The Survey of Innovation 1996 — surveyed the communications, financial and technical business services industries

The Survey of Innovation Advanced Technologies and Practices in Construction and Related Industries 1999 — first survey of advanced technologies and practices in the construction sector

The Survey of Innovation 1999 — surveyed manufacturing firms and was the first innovation survey of selected natural resources industries.

Source: Gault, Fred. 2003. *Understanding Innovation in Canadian Industry*, McGill Queens University Press.

The Statistics Canada 1999 survey on innovation surveyed firms in the manufacturing sector and, for the first time, select resource industries were surveyed (Schaan, 2003). Statistics Canada's survey, however, did not identify the oil and gas upstream sector, a major part of the energy and resources sector, thus leaving a major gap not only in the innovation data but also in our understanding of this key sector and that of Canada's innovation system. This may be due, in part, to the fact that the sector is complex and conventional surveys geared to manufacturing may not be applied easily to the industry in general. Industry Canada recognized this gap at the Industry Canada Conference on Innovation (2002) and stressed that more sectoral analyses needed to be done to understand innovation in the oil and gas and natural resource sectors. It was recognized also that questions in the survey were more

suitable for the manufacturing sector than the natural resources sector. Globerman (2002) argues that case studies of innovations provide another approach to look at public and private returns on innovations.⁵ Mowery and Rosenberg (1993) maintain that diffusion of innovations is often accompanied by learning about their use in different environments, and that this in turn feeds back into the original system of innovation.

⁵ Globerman (2002) notes that case studies are consistent with econometric approach of looking at innovation.

1.4 Research Objectives of Thesis

This thesis investigates the factors that drive oil and natural gas firms to innovate and the ways such innovation affects performance. The impact of six advanced major types of technologies on key performance indicators is examined, including cost, exploration and development drilling success rates, productivity, productive capacity (adding to reserves, new field development, projects), and mitigation of environmental impacts. The focus of the thesis is technological process innovation, which involves adoption and implementation of a new or significantly improved production process; this is distinct from product innovation, which involves the development and commercialization of a product with improved characteristics to deliver new services to the consumer. De Melto, *et al.*, (1980) found that, in the crude petroleum industry, nearly all reported innovations are process innovations.

The thesis provides a comprehensive review of the literature. An investigative framework, based on the innovation literature and the upstream oil and gas industry, is developed to examine the drivers of innovation and the impact of innovation on performance in the upstream petroleum sector. The research employs a survey questionnaire developed to obtain data and information that were missing in the literature and not publicly available to test key relationships of innovation and performance indicators. The survey questionnaire is included in Appendix 4. Companies involved in exploration, development, and production in the upstream petroleum activities were surveyed. The survey data are analysed using several statistical techniques, including multiple and logistic regression analyses. Undertaking a survey is a major and complex exercise and it was recognized in advance of this undertaking

that the survey faced uncertain response; considering the time required to fill out surveys, response rates can be low. In view of this, some potential respondents were contacted by telephone. As well, due to the competitive nature of the industry, there could be sensitivities and reluctance in responding to the survey questionnaire.

1.5 Investigative Questions

The research objective, in terms of investigating the drivers of innovation and the impact of innovation on performance in the upstream petroleum sector is achieved through four investigative questions (provided below). These questions seek to capture the drivers and the impact on key performance indicators that are relevant to the sector. These include exploration, development, and operating costs; productivity; productive capacity (adding to reserves, new field development and projects, recovery factors); exploration success; and the mitigation of environmental impacts. The four investigative questions are presented below (and also in Figure 1.1):

1. What are the most important factors that drive firms to adopt advanced technologies in the sector?
2. How important are the various modes (R&D, acquisition of advanced/modern and equipment, and acquisition of advanced processes) of innovation to the sector?
3. What is the extent of the use of advanced major technologies in the sector?
4. What is the impact of the application of advanced major technologies on performance (e.g., costs, output, environment, and producer netbacks) in this sector?

Figure 1.1: Drivers of Innovation and Performance in the Upstream Oil and Gas Sector

In addition to the four questions above, the following two questions were investigated to provide a broader understanding of innovation in the upstream sector:

1. How does collaboration (active participation in joint projects among firms, and other firms and organizations, including federal and provincial governments, in developing advanced technologies and processes for use in upstream activities take place in this sector?
2. How important are governments' policies and programs to innovation in this sector?

These two questions are also of interest from a public perspective. Sharpe (2003) notes that innovation is now a government-wide interest and priority, and that Statistics Canada, Industry Canada, the National Research Council, Natural Resources Canada, and other

departments and agencies (both federal and provincial) are interested in tracking innovation in their respective sectors. Consultations with experts and management within NRCan revealed that there is strong interest in understanding how innovation occurs within the natural resources sector, and the link between innovation and productivity and performance. There is need to understand the effectiveness of the Scientific Research and Experimental Development (SR&ED) tax credit in the natural resources sector (Sharpe, 2005). SR&ED is one of the largest government programs to stimulate R&D. NRCan workshop of March 2005, also called for analysis to understand how the program is used in the natural resources sector as well as its effective. The Conservative Party of Canada Platform (2006) and Budget 2007 (Finance Canada, 2007) made reference to this program in the context of looking at it for possible expansion. More information on the program is highlighted in Chapter 2 and in Appendix 3.

1.6 Organization

The rest of this thesis is organized as follows:

- Chapter 2 provides a review of the relevant innovation and technology literature, including the definition of innovation (including product and process innovation); and the system of innovation. It also looks at technology development and sources, including R&D; modes of technology acquisition; innovation and firm size; clusters and spillover effects; the rationale for, and impact of innovation; collaboration; and the role of government in spurring innovation. These facets of innovation are important for understanding the innovation system of a country, a sector of the economy, and an industry. This information will be used in conjunction with an

analysis of the upstream oil and gas sector to develop the investigative framework and the survey instrument.

- Chapter 3 situates the upstream oil and gas sector within Canada's energy and natural resources sector. It provides an overview of the upstream oil and gas sector, its special features, its strategic importance within the context of the energy and resources sector and the Canadian economy, the application of technology in the sector and reasons and challenges for the application of technology. Based on the review of the literature in Chapter 2 and analysis of the upstream oil and sector, six investigative questions are presented. This framework provides the basis for the survey instrument.
- Chapter 4 develops the investigative framework based on a survey of the innovation literature and of the upstream sector. The framework captures the drivers of innovation, the modes of innovation, and the impact of major technologies on performance.
- Chapter 5 outlines the methodology used for this study. In particular, it discusses how the data are collected using a survey questionnaire and the types of analyses that are undertaken in this study.
- Chapter 6 presents various types of descriptive statistics of the responses to the survey questionnaire used in this research.

- Chapter 7 focuses on inferential data analyses on the drivers of innovation and their impacts on performance.
- Chapter 8 provides analyses of the data on collaboration in the upstream oil and gas sector.
- Chapter 9 analyses the role of government in the sector.
- Chapter 10 presents a discussion of the results. Knowledgeable experts in industry and government were consulted and insights from the discussions are presented.
- Chapter 11 provides overall conclusions and recommendations. The thesis concludes by making recommendations and suggesting further areas of research that would complement the findings of this study.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a review of the relevant innovation and technology literature, including: the definition of innovation comprising product and process innovation; the system of innovation, technology development and sources including R&D, innovation and firm size; collaboration, clusters and spillover effects; the role of government and the impact of innovation on performance. These facets of innovation are important for understanding the innovation system of a country, a sector of the economy, and an industry. This information will be used in examining innovation in Canada and the upstream petroleum sector. It is used in conjunction with information in the upstream sector to develop the investigative, framework and the survey instrument.

What does innovation include?

The term “innovation” encompasses much more than R&D or technological change. Innovation makes knowledge useful and turns it into wealth and prosperity. However, innovation does not come out of the blue. It requires investment in a variety of activities, such as bright ideas, learning systems, training, R&D, technology commercialization, corporate culture, and entrepreneurial spirit.

Source: Conference Board of Canada (CBOC). 2001a. *Investing in Innovation: 3rd Annual Innovation Report*.

Advances in technology are widely regarded as important in improving competitiveness, from a firm’s, industry’s and country’s standpoint. In spite of the importance of innovation, our understanding of the innovation process, and its economic impact is still deficient. A firm’s ability to keep up with technological progress and continuously innovate is critical for survival and growth (Cardozo, *et al.*, 1993; Manu and Sriram, 1996; Guan, *et al.*, 2005).

Innovation underlies a country's standard of living, productivity, competitiveness, and environmental, economic, and social well being (Rosenbloom and Abernathy, 1982; Conference Board of Canada ((CBOC)), 2003; OECD 2003b; Baldwin and Hanel, 2003). Among process inventions that have greatly increased productivity was the Hall process for producing aluminum, the Bessemer process for producing steel, and automatic looms that replaced earlier hand looms (Samuelson and Nordhaus 1989). As a result of technological progress, capital, output, and real wages per worker grow over time.

According to Industry Canada (2002), the importance of innovation has even increased further given today's knowledge-based economy. Competition among firms accelerates the diffusion, application, and improvements in technologies. Similarly, there are several barriers to innovation, including risks related to the feasibility of the project, marketing risks, lack of equity capital, lack of equipment, shortage of qualified staff, risks of the innovation being copied by other firms, and regulatory risks (Mohnen and Rosa, 1999). The WEF's *Global Competitiveness Report* of 2006 demonstrates that technological innovation is a critical factor for productivity growth and standard of living.⁶ Productivity reflects how efficiently output can be generated from a given level of inputs in the process of production. The process of innovation is difficult to comprehend, as various processes often occur simultaneously at different levels (Tornatzky and Fleischer, 1990).

⁶ WEF's *Global Competitiveness Report* develops a (*Growth Competitiveness Index (GCI)*), which is utilized in the analyses of an economy's potential for economic growth and its current economic performance. The index is heavily weighted to the level of technological innovation. In the 2003 report, Finland ranked first, followed by the US, Sweden, and Denmark on the GCI. Canada fell to 16th place on the GCI. The 2006 report shows the U.S. dropping in rank and Canada remaining at the same level.

2.1 Definition of Innovation

The word innovation can have different meanings in different contexts and the one chosen will depend on the particular analysis of the measurement (CBOC, 2001a). Table 2.1 provides several selected definitions of innovation.

Table 2.1

Selected Definitions of Innovation

Rao, <i>et al.</i> , 2002	Innovation is a continuous process of learning, discovering, and applying new technologies and techniques from many sources.
Bernstein, 2002	Generally, innovation can be thought of as the introduction and adoption of new processes and products.
Industry Canada (2002)	Through innovation, knowledge is applied to the development of new products and services or to new ways of designing, producing or marketing an existing product or service for private and public markets. The term “innovation” refers to the <i>world first</i> new to Canada or simply new to the organization that applies it.
Conference Board of Canada (2001a)	Innovation is the process through which economic value is extracted from knowledge through the generation, development and implementation of ideas to produce new or improved products, processes and services.
Baldwin, <i>et al.</i> , 2000	Innovations differ in several aspects. They vary in nature - product or process - and importance - radical or imitative. A product innovation is the commercial adoption of a brand new product of higher quality. A process innovation is the use of new or improved production methods, that lead to a reduction in unit costs.
<i>Oslo Manual</i> , OECD 1997	A technological product innovation is the development and commercialization of a product with improved performance product characteristics such as delivering objectively new or improved services to the consumer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods, or a combination of these.
Sirilli and Evangelita, 1998	An innovation has been implemented if it has been introduced on the market (service innovation) or has been used within a production or delivery process (process innovation).
Palda, 1993	A firm, an industry, and an economy’s innovativeness can be envisaged as consisting of both types of activities - the creation as well as the adoption/diffusion of innovation.

Most of the definitions presented in Table 2.1 highlight the difference of product and process innovation. This distinction is important according to Kraft (1990). Innovation involves various stages, the generation of ideas (sometimes termed knowledge creation), development and implementation of them.

Deriving competitive advantage from innovation is a highly intricate process that involves technical complexities, functional interdependences, evolving solutions, high levels of uncertainty, and highly complex forms of integration (Veugelers and Cassiman, 1999; Drucker, 1998; Thamhain, 2003; Tushman, *et al.*, 1999). Faems, *et al.*, (2005) note that designing and implementing an innovation strategy is directly related to the multitude of objectives. It is not surprising, therefore, that measuring innovation and its impact can be a significant challenge (Sirilli and Evangelista, 1998; Martin and Milway, 2005).

The *Oslo Manual*⁷ defines innovation with respect to technological product and process innovation. The *Oslo Manual*, prepared by the OECD, is considered an authoritative document on collecting and interpreting innovation data.⁸ It provides guidelines on how innovation can be assessed across countries. The *Oslo Manual* (OECD, 1997, p. 9) notes that:

⁷ The *Oslo Manual* (OECD / Eurostat 1997) is considered as a textbook on innovation and national systems of innovation, and a compendium of socio-economic questions on the nature of innovation in market oriented economies. The *Oslo Manual* provides guidelines for the measurement of innovation.

⁸ Holbrook and Hughes (2002a) argue that Oslo Manual uses the first two of five types of innovation presented in the classic work of Joseph Schumpeter. The five types of innovation defined by Joseph Schumpeter (1934) are: introduction of a new product or qualitative change in an existing product; process innovation new to an industry; the opening of a new market; development of new sources of supply for raw materials or other inputs; and changes in industrial organization.

A technological product innovation is the development and commercialization of a product with improved performance product characteristics such as to deliver objectively new or improved services to the consumer. A technological process innovation is the implementation/adoption of new or significantly improved production or delivery methods. It may involve changes in equipment, human resources, working methods or a combination of these.

Abernathy and Utterbach (1978) note that although many observers emphasise new-product innovation, process and incremental innovations may have equal or even greater commercial importance and that a high rate of productivity improvement is associated with process improvement. Rather than the generation of new technology, it is its diffusion throughout the economy and adoption by firms that affects productivity and growth (Arvanitis and Hollenstein, 2001). According to Rao, *et al.*, (2001), the greater part of innovation in Canada consists of applied innovation that occurs when new products or processes developed either in Canada or in other countries, especially the United States, are utilized in Canadian-based firms. Hamdani (2001) notes that firms focussing on process innovations seek to expand market shares through operational efficiency while firms involved in product innovation seek expansion in markets through introduction of new products. Similarly, Baldwin and Johnson (1997) and Baldwin (1998) note that firms involved in process innovation place little value in developing new products.

In choosing a definition of innovation for this thesis, it is crucial to recognize that the innovative character of the upstream oil and gas sector of the resources industry differs from that of the information communications technology (ICT) industry. For example, it is more focussed on process innovation than product innovation. These innovations are often

associated with very large capital investments and take a long time to develop. Innovations in the sector also have a long life cycle from basic research through to development, commercialization and adoption. Tortnatzky and Klein (1982) note that innovation research studies should focus more on adoption and implementation as the dependent variables, and not simply dichotomous yes / no adoption decisions.

The sector focuses more on improving processes than on developing value-added products. Drawing from the *Oslo Manual* (1997), Baldwin, *et al.*, (2000), Schumpeter (1934), Holbrook (2002), Tang (2003a) and others, the term innovation is used in this paper to mean the application of a new or improved method in the process of production in exploring for, developing, and producing oil and natural gas.

2.2 System of Innovation

The system of innovation involves a number of key elements concerned with the generation, dissemination, and application of new knowledge: R&D to provide new ideas; education and information services to develop the required personnel; and design engineering and marketing services to incorporate the new ideas into production and distribution systems (Statistics Canada, 2001, Nelson 1993). Boyd and Inch (2003, p. 6) note: “For the firm to be innovative, it needs skilled people, a risk accepting culture, access to venture capital, and a regulatory environment that support entrepreneurial activity.”

The OECD (1997) notes that a national innovation system is a set of distinct institutions that jointly and individually contribute to the development and diffusion of new technologies and that provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of inter-connected institutions to create and store the knowledge, skills, and artefacts that defines new technologies. From this perspective, innovative performance of an economy depends not only on how the individual institutions (firms, research institutes, universities, etc.) perform in isolation but also on how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal frameworks, and so on) (OECD, 1998).

Figure 2.1: The Natural Resources Sector - System of Innovation

Source: Conference Board of Canada. 2001. *Members Briefing: Investing in Innovation in the Resource Sector*.

OECD (1998) notes that because of their unique history, production, and innovation systems have different specialization patterns, capital stock, and institutions. Countries can be viewed as “national innovation systems,” with distinctive attributes (specific scientific, technological and industrial specialization, and specific policy priorities) and specific structures of interactions (e.g., between science sectors and science system collaboration among firms). Innovation systems are increasingly linked across national borders. Nevertheless, national characteristics and the strengths and weaknesses of the respective

systems remain decisive for performance. Given their uniqueness, policy responses may differ significantly across countries (Nelson, 1993).

The sector's system of innovation is unique and complex. The system is multidimensional with linkages along the supply and value chain (Figure 2.1). It includes producers, upstream suppliers, and "downstream" value-added producers and manufacturers. These are separate entities where value is added in each production stage and they interact with governments, suppliers, consumers, and the global market place. The highly complex nature of the sector and its inter-relationships with government, consumers, the global market place, and suppliers have significant implications for the way in which innovation and R&D take place and are measured. Service, engineering, and supplier industries are an important part of the innovation chains of these sectors. Laestadius (1998) notes that this makes it difficult to measure innovation and R&D effort in the sector.

2.3 Technology Development and Sources

Technological innovation is not a single event nor is it made up of a small number of discrete events. Technological changes include small improvements in machines and the organization of labour, arising from the slow processes of learning by doing or learning by using and from major or radical changes. Incremental changes (or minor innovations) are innumerable and occur more or less continuously in any industry (Rosenberg, 1994). Major or radical changes are usually termed discontinuous events which spawn other changes

(Steele, 1989). Some major technological advances will change the boundaries or rules of competition (Schumpeter, 1934; Dror, 1988; Hart and Milstein, 1999).

One way of appreciating the vast number of discrete events that are encompassed in the process of technological innovation is to realize how long the process takes to unfold – from initial idea generation (which may or may not derive directly from scientific research) to widespread use of technological innovation by an appropriate population of users – the time may range from months to decades. Environmental pressures exerted by a user community may accelerate the overall process. The span is also correlated with the number of people involved. This number may range from the thousands involved in the development, design, and manufacture of a nuclear submarine to a few person-months needed for a more defined technology, such as a computer program (Tornatzky and Fleischer, 1990).

2.3.1 Research and Development

Research and Development (R&D) is usually defined as creative work undertaken on a systematic basis in order to increase the stock of knowledge according to the OECD's 2002 *Frascati Manual*.⁹ It is vital for innovation and technological progress and is linked to economic success (Cohen and Klepper, 1996; IC 2001; Szakonyi 1998). According to Hamdani (2001), path breaking innovations are less likely to happen without it. Innovation, however, extends beyond R&D (Holbrook, 2002). Kline and Rosenberg (1986) introduced

⁹ The *Frascati Manual* was first prepared in 1963 in Frascati Italy; the 6th edition was published in 2002. It is a document stipulating the methodology for collecting and using statistics about R&D in countries that are members of the OECD.

the “chain link” model, which recognizes not only the importance of R&D but of other measures of innovation. Baldwin and Hanel (2003) argue that while there is a close relationship between R&D and innovation, there is also a close relationship between the adoption of advanced technologies and innovation. As will be noted later, while R&D is essential to the creation of new knowledge, it is not the only or best indicator of innovation.

Nonetheless, R&D expenditures are widely used as a proxy measure of innovation. The popular approach to assess the adequacy of R&D is to quantify the amount of money spent on R&D as a percentage of sales (Holbrook and Squires, 1996). Whereas patent and innovation counts are termed output-based measures of innovation, R&D spending is an input-based measure. The link between output-based and input-based measures of innovation activity has been established for a number of countries. Griliches (1990) surveys this literature and finds a strong correlation and contemporaneous relationship between patents (output-based) and R&D. Globerman (2002) notes that although some organizations perform relatively small amounts of R&D, this does not necessarily suggest that R&D is unimportant to innovation outcomes. Rather, it might suggest that R&D expenditures are poor proxies for the actual rate of knowledge accumulation. Baldwin and Hanel (2003), Sharpe, 2005, and Persaud, *et al.*, (2007) maintain that R&D may be a misleading indicator of the level of innovation.

Firms can benefit by investing in R&D in two ways (Globerman, *et al.*, 1999). First they can reduce their production costs or improve their product quality relative to other firms.

Second, they can introduce new products into the marketplace.¹⁰ R&D is an input to the generation of new technology but not necessarily the measure of the use of new technology, and as such may not be an ideal measure of innovation. Further, according to Holbrook (2002), innovation extends beyond R&D. Although neither a necessary nor sufficient condition for innovation, R&D is an important input to the innovation process (Baldwin, 1997b).

2.3.2 External Sources of Technology

Technology can be sourced from R&D done inside the firm (intramural) and outside the firm (extramural) and from the outside through acquisition (OECD [*Oslo Manual*], 1997). Relatively few firms are able to support the science-based R&D in existing and emerging business (Teece, 1986). The *Oslo Manual* provides an exhaustive list of sources of innovation. Many important technologies used in the value chain are outside of a firm's technological capabilities. While internal sourcing may be necessary for the firm's core technologies, some may have to be sourced externally through licenses, contracts, or alliances (Burgelman *et al.*, 1996). Contracts are considered discrete and alliances ongoing. Viewing the issue of external sourcing from this perspective highlights the importance of managing dependencies.

¹⁰ Although these are the economic arguments, there are other factors involved in the decision of firms to innovate, e.g., corporate culture.

2.4 Life Cycle and Innovation

The life cycle notion involves two sets of activities. The first set deals with the creation, nurturing, and delivery of new technologies and the second set, often thought of as research proper, includes the invention of new products and processes innovation.¹¹ Life cycle models have certain comforting appeal but there are distinct limitations to this approach. Innovation is often conceived of as a linear process – going from basic research through to engineering and commercial production. Kline and Rosenberg (1986) note that the “linear model” distorts reality. According to Tornatzky and Fleischer (1990), innovation is not at all simple or linear. An essential requirement of the definition of R&D is that the outcome of the work is uncertain (SC, 1989). The Council of Canadian Academies (2006, p.1) note that “There is no linear progression from research through invention to innovations. Instead, the process involves false starts, blind alleys and feedback loops, and it includes obstacles that have little to do with the quality of S&T involved.” When the linear model is appropriate, the main difficulty in measuring R&D involves the definition of the dividing point between the research process and commercialization stage. In addition, R&D is a small part of the total innovative effort, especially in a small open economy such as Canada. A substantial amount of machinery and equipment are imported into Canada embodying R&D.

Investments in R&D and in human resources (especially scientists and engineers) are crucial prerequisites for fostering fundamental innovation. Baldwin and Johnson (1997) note that

¹¹ Innovation can take the form of organizational and marketing changes that expand the demand for products, support existing structures for new methods of production and increase the efficiency of other types of innovative efforts, leading to productivity improvements.

the concerns over lack of skilled labour are consistent with R&D firms. Fundamental innovation also depends on supporting institutions (universities and government labs) the business environment, and sound market framework policies (e.g., competition, intellectual properties). Like fundamental innovation, applied innovation is also linked to investments in R&D and human capital (Baldwin, *et al.*, 1999). In addition, applied innovation requires investments in machines and equipment (M&E) and strong international links for the diffusion of new innovative processes and techniques.

According to the Mining Association of Canada (MAC, 2000), most mining companies perform R&D in order to improve competitiveness. They undertake R&D to reduce costs and improve productivity by developing new processes and improving existing processes. Firms were not focussed on innovations to develop new products to increase value added. Mining companies also consider environmental compliance as a strong priority.

The CBOC (1994) found that the majority of companies awarded top rank to the cost reduction objective, followed by adding value to existing products and environment as the main reasons for doing R&D. Global competition has been increasingly squeezing profit margins in the resource sector in the areas of forestry and mining but not in oil and gas in recent years. These competitive pressures can be addressed by resource firms using technology effectively to reduce costs. Non-resource companies saw developing new products and gaining market shares as the most important goals. The vast majority of R&D, including R&D directly and indirectly applicable to natural resources, seems to take place outside Canada.

2.5 Innovation and Firm Size

Firm size and innovation have been in the forefront of studies since Schumpeter's theory associated successful innovation with larger firms (Schumpeter, 1975). His work is considered the starting point of the literature on competition and innovation (Boone and Dijk, 1998). The Schumpeterian hypotheses state that firm size and monopoly power (industry concentration) affect the incentives to innovate. Arvanitis and Hollenstein (2001) note that size and age are two explanatory variables used in most studies on adoption. For the most part, it is argued that larger firms have easier access to financing and can spread the costs of innovation over a larger volume of sales, and benefit from economies of scope and complementarities between R&D and other manufacturing activities (Bajwa and Lewis, 2003). Large firms also tend to undertake riskier projects (Patel and Pavitt, 1991). Small firms are considered to have cost disadvantages in terms of R&D, but also have advantages including meeting customer needs, flexibility, better response times, and managerial control. Firm size is expected to be positively related to adoption. Although the relationship between the size of firms and innovation has received much attention in recent studies, the evidence seems to be inconclusive (Arvanitis and Hollenstein, 1996; Tang 2003b; Levin and Reiss, 1988). Mazzucato (2000) argues that there is no single answer to whether small firms or large firms are more innovative, but that instead it varies by industry. Grover and Golsar (1993) found no significant relationship between organization size and innovation, adoption, and implementation of telecommunication technologies in the U.S. Cohen *et al.*, found that firm size has an insignificant impact on R&D. Studies by Dasgupta and Stiglitz (1980a) and Baldwin (1997b) suggest that size and innovation are mutually dependent. Swamidas (2003)

found that small firms are slower than larger firms to adopt manufacturing innovations in the U.S. Soete (1979) found that R&D intensity increased with size in a number of sectors in the U.S. Dewar and Dutton (1986) argue that larger firms are likely to have more technical specialists and to adopt radical innovation; further economies of scale may also operate allowing larger organizations to take the financial risks entailed in radical changes of their processes.

A study of innovative firms in five industries in Canada has also indicated that the R&D intensity of small firms can be as high as, and even higher than, that of large firms (De Melto *et al.*, 1980). The study shows that the smaller firms are at least as R&D intensive as the bigger firms in terms of the R&D sales ratio, and more intensive in the ratio of R&D expenditure per employee. Bajwa and Lewis (2003) show that the adoption rates of small firms in information technology (IT) clusters are higher for large firms. Cohen, *et al.*, (1987) found that neither firm nor business unit size had any statistically significant effect on R&D intensity. Acs and Audretsch (1987, 1988), using innovation data published by the U.S. Small Business Administration, argued that SMEs may be even more innovative than larger firms. It has also been argued that attention is being focussed in the literature on the development of special support for small firms (Acs and Audretsch, 1990). Baldwin, *et al.*, (1995b) maintain that there is great interest in smaller firms because of the amount of employment generated by small firms.

2.6 Clusters and Spillover Effects

Interest in regional clusters has grown significantly in recent years. A cluster is a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities (Henderson and Trajtenberg, Porter, 1998b; 1993, Porter, 2000a; Porter, 2000b). Enright (1998) notes that clusters can provide the environment to innovate. The transfer of knowledge from one firm to another is called knowledge spillover.¹² Dasgupta and Stiglitz (1980b) argue that spillover externalities are the driving force behind economic growth. Griliches (1992) argues that spillovers account for up to half the growth in output per employee and about 75 percent of the measured total productivity (TFP) growth in the United States. Many cluster advantages rest on external economies or spillovers across firms and industries. Keller (2001) finds that the spillover effect of a dollar investment of R&D in the U.S. is quite high in Canada. Using Keller's study, Harris (2005) estimates that because U.S. R&D spending is about 40 times larger than Canada's, U.S. spending is more important for Canadian productivity than is Canada's own.

Arrow (1962) takes the view that spillovers occur more readily between firms in the same industry, and that a concentration of industrial activity in one geographic area should accelerate economic growth. Porter (1990) argues that geographically concentrated

¹² Economists call this a positive externality. In 1890, Alfred Marshall wrote that the concentration of industry in cities allows knowledge to spread from firm to firm rapidly, and this should fuel economic growth. Arrow (1962) formalized this idea, and Romer 1986 restates this.

industries spur growth. He argues, moreover, that intense competition makes innovation essential to corporate survival and that this overwhelms the problem of innovations falling into competitor's hands. Spillovers can also occur across industries. Rosenberg (1994) found that 70 percent of the inventions in a given industry are applied in other industries.

2.7 Rationale for and Impact of Innovation

Companies undertake innovation to reduce costs, and improve productivity and competitiveness (Porter, 1990; CBOC, 1999; CBOC, 2001b; Mitropoulos and Tatum 2000; Martin and Porter, 2001). Competitive pressures often drive firms to adopt new technologies to differentiate themselves from competitors and to gain cost advantage (Mansfield, 1986; Porter, 1985b). Schumpeter demonstrated that innovation violates one of the key assumptions of neoclassical microeconomic theory, i.e., that competitive firms, producing similar outputs, depended on similar inputs. Improved health and safety also rank as important drivers of R&D (Mitropoulos and Tatum, 2000). Firms that can develop innovative and cheaper ways of producing existing goods can lower their costs and can make extra profits from the prevailing price of their output. Firms that develop new and better products can similarly earn excess profits greater than their input costs because they alone can produce the new products. In both cases, innovation gives the firm a degree of monopoly power. Technological progress directly increases the productivity of innovating firms and indirectly increases economy-wide productivity through its diffusion and adoption.

Technology is responsible for many of the important changes in our society and for determining corporate success, profitability, and growth. Emerging technologies bring not only new opportunities to grasp, but also threaten to replace old ones (Burgelman, *et al.*, 1996). The critical importance of technology is lodged in the dynamic aspect of the concept, i.e., technological change. Technology can be considered to be an ensemble of theoretical and practical knowledge, know-how, skills, and artefacts that are used by the firm to develop, produce, and deliver its products and services (Gerwin and Kolodny, 1992; Burgelman, *et al.*, 1996). Technology is considered important to the success and survival of individual companies and one of the principal drivers of competition in industries (Porter, 1985b; Burgelman, *et al.*, 1996).

The link between technological innovation and productivity growth receives particular attention in the literature (Rao, *et al.*, 2002; Sharpe, 2003; OECD, 2003c). Innovation is often thought of as the “engine of growth” because of the lasting effects on productivity. The literature confirms the existence of a relationship between R&D and productivity and profitability (Kamien and Schwartz, 1985; Kam, *et al.*, 2003; Baldwin and Zhengxi, 2002). Rao, *et al.*, (2002) find that for 1995 and 1997, a one percent increase in R&D personnel per 1000 population led to 0.8 percent increase in the number of patents granted in the United States. Roberts (2001) found a strong correlation between R&D intensity and sales from new products as well as between R&D intensity and the overall newness of a firm’s technology emphasising R&D as a vital area for company success.

Rao, *et al.*, (2002) estimates that a one percent increase in the number of patents per million persons granted in the United States leads to a 0.63 percent increase in a country's living standard. Morck and Yeung (2000) find that a one percent increase in innovation, measured simply by patents, leads to a .63 percent in a country's living standard, measured by per capita GDP. There are several factors including the shift to a more service-oriented economy and the lag between the time when an innovation takes place and when it is translated to productivity gains. Another difficulty is disentangling the impact of technology from that of other factors affecting productivity, such as infrastructure, demographic change, international trade and the degree of competition. Economy-wide productivity gains from new technologies are mainly generated during the process of diffusion of new products and processes throughout the economy. Arvanitis and Hollenstein (2001) note that, rather than the generation of new technology, it is its diffusion throughout the economy that affects economic growth. Although the conceptual links between innovation and productivity are strong, the nature of the relationship between the two is complex (Rao, *et al.*, 2002).

The impact of technology on productivity is crucially conditioned by the policy environment and the framework conditions within which firms operate. Arvanitis and Hollenstein (2001) argue that it is not surprising that technology policy stresses the importance of an improvement of a firm's capacity to successfully absorb technological knowledge. Excessive taxation and distortionary taxes will inhibit the development, diffusion, and adoption of new technologies. OECD (1998) studies for the United States, Canada, and other countries have found that technology users are more productive than non-technology users. Acharya and Coulombe (2006) argue that R&D is a good candidate to accelerate growth as it brings

technological progress and it also increases the absorptive capacity of the domestic economy to capture spillover from foreign R&D. Swamidass (2000) found that a significant percentage of U.S. manufacturers report manufacturing cycle time reduction, manufacturing cost reduction, production line increase, and rate of return on investment increases as a result of the use of manufacturing technology.

Advanced manufacturing technologies (AMT) bring about many benefits, including reduced costs, improved product quality, higher efficiency, and increased product/process flexibility (Gerwin, 1994; Meredith, 1987; Zhao and Co, 1997; Kumar, *et al.*, 1996). Hayes and Jaikumar (1991) show in their study of 20 flexible manufacturing systems that firms can reduce labour requirements by as much as 88 percent and costs by 25-75 percent. Huang and Sakurai (1989), in their study of manufacturing firms in Japan, show that the reduction in labour costs tops the list, followed by quality improvement. Other benefits include set-up time reduction, improved utilization and productivity, reduced labor requirements, and marketing advantage. Somers and Gupta (1991) surveyed 268 manufacturing firms and compared the results with those of Huang and Sakurai (1989) and found that quality improvements, lead times and labour costs were the major benefits of innovation. Investing in computer controlled manufacturing processes can result in considerable payoffs as valuable information can be collected on line for immediate analysis and subsequent modification (Zhao and Co, 1997). Kumar, *et al.*, (1996) suggest that more detailed research could be performed on the impact of the investment scope, firm size, experience in AMT investments, and the resulting satisfaction with the adopted technology.

Solow (1988), in his pioneering methods in detecting the determinants of economic growth, attributes one-third of the U.S. growth between 1929 and 1982 to technological progress. Morck and Yeung (2002) argue that countries that show evidence of innovation are richer and grow faster. Heintze and Bretschneider (2000) show that the adoption of information technology has a direct effect on performance. Mansfield (1996) found that the average rates of return on innovation were quite high, ranging from 30-50 percent (social rates, i.e., not after tax). Productivity gains drive economic growth, so understanding the impact of technology in the growth process requires examining how it affects productivity at the micro and macro levels. At the firm level, it is difficult to establish a clear link between an indicator of technology effort such as R&D and productivity growth (OECD, 1998; Mohnen, 1992; Bernstein, 2002).

2.8 Collaboration and Innovation

Although innovation is critical for improving competitiveness, it is becoming increasingly difficult for firms to develop new technologies on their own as a result of limited expertise and resources (Hamel and Prahalad, 1994). Leiponen (2000a) concluded that, nowadays, performing R&D alone is insufficient for producing profitable innovation. Significant emphasis is placed in the literature on collaboration as being an important driving force for innovation (Teece 1986; Nakamura, *et al.*, 1997). Collaboration between industry and research institutes and universities is helpful in reducing the cost of R&D, reducing risks, facilitating the sharing of resources, and achieving complimentary capability (Guan, *et al.*,

2005). Cooperative research can take several forms, for example, support in terms of money, advice, and sharing of research reports (Tornatzky 1990). OECD (2000) stresses that collaboration is becoming an essential part of the innovation system because of the increasing complexity of technologies, speed involved in innovation, and the difficulty of mastering all the specific fields required to innovate.¹³ Collaborations take place in numerous settings, for example, with existing suppliers, users, university research centres / institutes, and competitors (Hamel, 1991; Gerwin, and Kolodny, 1992; Guan, *et al.*, 2005).

There are many reasons for collaborative research, including cost and risk sharing, accessing new knowledge and markets, gaining expertise, coordinating strategies, maximizing return on resources, and enhancing efficiency by preventing needless duplication (Baldwin and Hanel, 2003; OECD, 2000a Guan, *et al.*, 2005). One of the key drivers of consortia has been the globalization of world markets (Kumar and Magun, 1995). The view that collaboration has great potential to contribute to innovation strategies does not mean that all collaborations are successful; in fact a large number of them fail (Faems, *et al.*, 2005). Spillovers, lack of flexibility and adaptability are all cited as reasons for failure (Veugelers, 1998; Doz 1996; Teece, 2002). Despite these drawbacks, collaboration is still considered important for performance.

¹³ Contract research enables a firm to incorporate new ideas when the internal expertise does not exist. This involves third parties and is a market based transaction. Collaborative research involves partnerships and extends the boundaries of the firm (Baldwin and Hanel, 2003).

In Canada, financial pressures in the mid-90s have led to an emphasis on collaborative R&D to reduce costs and to achieve a critical mass of funding in the energy sector (CBOC, 2000). Therrien and Chang (2003) note that the most frequently mentioned benefit derived from collaboration is the mutual exchange of ideas. Collaborative agreements extend across a wide range of partners (customers, suppliers, affiliated companies, competitors, R&D institutions, and universities in both Canada and the United States. The CBOC (2000) in its report *Collaborating on Innovation* noted that firms with a greater propensity to cooperate in developing technologies are more likely to produce innovations than those that collaborate less. *Achieving Excellence, Canada's Innovation Strategy*, highlights the increasing involvement of government laboratories in partnerships. Resource sector stakeholders at the National Round Table on Innovation also stressed the importance of national collaborative efforts in addressing innovation and sustainable development challenges.

The literature identifies problems associated with collaborative agreements. For example, “group think” may reinforce old ideas, thus hindering or slowing down the rate of innovation. Horibe (2001) notes that this could discourage radical innovation. There may be opportunities for free riders or some firms may try to extract most or all of the gains. There may also be increased congestion (too many participants and or projects) created within a growing cluster which may have a negative effect on innovation (Porter, 1988b). Recent work by Therrien and Chang (2003) shows that local collaboration as well as other types of collaboration have a positive impact on innovation. Their work shows that the involvement in local collaboration increased the probability of a firm's being a world first innovator by

4.5 percentage points while the marginal effect of other types of increased the probability by 3.9 percentage points.

With the increasing scope and range of multinational firms, foreign firms are now more technologically sophisticated and, as a result; technology is more internationally mobile. Nelson (1993) notes that the competitive advantages that accrued in the past from U.S. basic research and strong knowledge base have been eroded and that faster international transfer of new technologies has undercut a major source of America's post-war superiority in high-technology markets. The formation of international consortia or alliances, domestic university-industry linkages, and new federal policies, including funding initiatives, has been a key response to regain competitive advantage.

2.9 Environment and Innovation

Porter (1998a) argues that one of the key reasons for environmental regulation is to create pressure that motivates companies to innovate and to raise the likelihood that product and process innovations in general will be friendly. Several theoretical papers have examined the abatement pressures stemming from environmental regulation and policy. Downing and White (1986) and Milliman and Prince (1989) show that the incentive to innovate is stronger under a market-based system (e.g., emissions fees or permits) than under command and control regulations. However, the notion that environmental regulation can motivate firms to innovate has received only limited empirical scrutiny in the literature (Brunnermeier and Cohen, 2003). Porter and van der Linde (1995) argue that environmental regulations would

not only pressure firms to innovate but ultimately this innovation will stimulate growth and competitiveness. The latter part of this claim has been subject to debate and criticism while the first part, although plausible, has been supported mainly by anecdotal information (Palmer and Portney, 1995; Brunnermeier and Cohen, 2003). The success and survival of individual companies rests on the application of technology according to Porter (1985a). Significant emphasis and commitment in funding has been recently placed on new technologies for addressing environmental problems, particularly clean air as noted above.

2.10 The Role of Government

This section discusses the importance of government policy with respect to innovation. Firms do not operate in an environment exclusively defined by markets, industry structures, and market opportunities. Firms operate in a political, legal, and fiscal context often influenced by government actions (Coombs, 1987). Dunning (1992, p. 43) notes that: "... by regulation, commissioning or funding R&D activities, both national governments and regional authorities may directly influence the level and structure of innovatory related activities." Further, the role of government in science and technology has been increasing in industrialized countries, but it has probably changed the fastest in the United States (Brooks, 1986). Government action is of vital importance to the technological progress and economic development of a country, and industrialized countries have recognized the importance of innovation (Nakumara, *et al.*, 1997; OECD 1998; Tasse, 2002, IC, 2002; Aggarwal, 2003). Brooks (1986) argues that government has been a source of much *generic technology* as well as fundamental science which has then served as a substrate for technological innovation by

the private industrial sector. Lazarus (2001, p. 30) argues that “the public in general and policy makers in particular need to view federal support in R&D not only as critical to maintaining our technological and economic leadership but also as an investment that pays significant returns to the government (via tax revenue) and society.”

Government support programs are expected to play a key role in a firm’s decision on whether or not to undertake an innovation activity. According to the CBOC (2002), to meet the challenge, a country must have an attractive policy environment to encourage increased industrial R&D investment, discourage the flight of R&D to foreign jurisdictions, and attract technology intensive investments from around the globe. Some countries like the UK and Australia have launched formal strategies while others, such as the U.S. and Sweden, even without formal strategies, have vigorously supported innovation (IC, 2001; OECD, 1998). The U.S., the most innovative country in the world by almost all measures, has a plethora of methods such as increasing R&D, funding basic research in universities, funding government laboratories, conducting large amounts of defence research, investing in schools, and developing partnerships (*Achieving Excellence*, 2002). The WEF (2003) ranks the United States number one in terms of patents. The CBOC (2003) ranks the U.S. as the most innovative country in terms of the number of parameters (R&D as a percentage of GDP, patents, researchers).

Government policy may influence a firm’s R&D and innovation through several key mechanisms, including patent and copyright policy (enforcement of firms’ rights to “intellectual property”); tax policy (R&D tax credits can alter effective costs and returns);

regulatory policy; and contracting out major defence, space, and energy R&D projects (Tornatzky and Fleischer, 1990). R&D strategies can also be affected by the regulatory environment in which corporations operate. Government regulations often aim to influence or control a firms' product or process as a means of achieving social goals. Government drug approval, passenger restraints, energy efficiency standards, and consumer safety and liability laws have a strong influence on the style and performance of new cars. Anti-trust regulations also seek to limit collusive activity. Government regulations also impact on compliance technology (e.g., minimum standards), product and process approvals, environmental standards and regulation, and rate setting (e.g., electricity).

Evidence suggests that the effectiveness of patents is industry specific. Mansfield (1986) interviewed 100 executives. Nearly one third in the pharmaceutical and chemical industries said that patents were essential; only 10 to 20 percent of those in petroleum, machinery, and fabricated metal products considered patents essential. Further, patents were considered to be of limited importance to executives in the electrical office equipment, motor vehicles, instruments, primary metals, rubber, and textile industries. An innovator's ability to enjoy the full benefits of its research by preventing imitation reflects anticipated monopoly power (Geroski, 1990). Levin (1986) reports that only in chemical and pharmaceutical industries were patents considered important. Teece (1986) argues that rarely, if ever, do patents confer total protection although they afford considerable protection for new chemical products (secrets can be better guarded) rather than mechanical inventions. Many patents can be "invented around" at modest costs. They are especially ineffective at protecting process innovations (Levin, 1986).

Almost all the industrialized countries now offer some sort of tax credit or tax benefits that increase their R&D spending (Brooks, 1986). Work on tax policy on R&D provides mixed results. Mansfield (1986) conducted surveys of firms in Canada and Sweden and found R&D spending to increase only minimally due to government incentives. Baily and Chakrabarti (1988) found that tax credit provided a significant outlay in R&D expenditure. Studies have attempted to quantify the effect of federal R&D contracts on a firm's decision to conduct its own, internally funded research. Lichtenberg (1984) cautions against the interpretation that federal contracting stimulates R&D spending. He points out a potential flaw in the many analyses; he notes that firms that already conduct a good deal of internal research may have an advantage in competing for federal government contracts. He concludes that what is missing from this type of analysis is a precise tracking of strands of technology development.

The government has long been involved in innovation in Canada since the establishment of the National Research Council in 1916. The federal government's substantive policy commitment to innovation policies in Canada, however, began largely in the 1970s in response to research showing that technological progress was a key determinant of economic prosperity and continued in the following decades (Industry Canada, 2006). This trend has continued in the new millennium and in 2002 Canada's *Innovation Strategy* was launched. The strategy recognized that the private sector needs to strengthen its ability to develop innovations for world markets and adopt leading-edge innovations from around the world. The strategy also recognized that the relatively low levels of investment in R&D, too few

strategic technology alliances, and limited pools of capital contribute to Canada's relatively poor innovation performance. Canada's *Innovation Strategy* announced targets by 2010 to at least double the Government of Canada's current investment in R&D and place Canada among to the top five countries in the world in terms of R&D performance.

Canada's SR&ED tax incentive system is considered to be one of the most generous in the world. The program provides a tax credit for qualifying SR&ED expenses incurred in Canada. The SR&ED tax credit system has been in place since the mid 1980s and the basic structure has changed very little during the last two decades. The last public information is from 2000, which indicated that there were 11,000 claimants with an estimated credit claim of \$1.7B in 2003 and \$2.6B for 2006 (Finance Canada, 2004). Although the program is large, there is very little public information on the program, particularly by sector, to assist carrying out detailed analytical work to understand the effectiveness of the program. Sharpe (2005) argues studies need to be done to understand whether the natural resources sector is making use of the program.

Almost all provinces provide some additional tax credits ranging from 10-15 percent (Quebec has the highest). Alberta is the only major province that does not have an R&D tax credit. A possible explanation is that Alberta actually provides an incentive for oil-and-gas related R&D but does so through its royalty holiday system or other royalty reduction incentives. For example, in areas such as ICT, medical research, and agriculture, Alberta provides focused tax credits or grants.

A more in-depth discussion of Canada's innovation policy and programs is provided in Appendix 3. Chapter 9 analyses the oil and natural gas industry's responses on the importance of government policies and programs.

CHAPTER 3

THE UPSTREAM OIL AND NATURAL GAS SECTOR: AN OVERVIEW AND ANALYSIS

This chapter situates the upstream oil and gas sector within Canada's energy and natural resources sectors. The chapter provides an overview of the upstream oil and gas sector, its special features, and its strategic importance within the context of the larger energy and resources sector and the Canadian economy. It also examines the application of technology in the sector, and concludes with the reasons for and challenges to the application of technology in this sector. In addition, key conceptual issues – including sustainable development, energy security, oil prices and market conditions, and oil and gas reserves – are discussed.

3.1 Canada's Natural Resources Sector

3.1.1 Overview

The upstream crude oil and natural gas sector is an important part of Canada's natural resources sectors. In order to situate the upstream oil and gas sector, it is worthwhile to briefly discuss the natural resources and energy sectors. The natural resources sector is defined in this thesis to include energy, minerals and metals, forestry, and earth sciences geomatics service industries and geoscience industries, but it excludes agriculture and fishing. The sector is closely linked to a broad group of allied industries, including supplier and service industries (e.g., biotechnology, environmental technologies and robotics). Canada's natural gas resources base is vast and includes both non-renewable sources (e.g.,

petroleum, natural gas and coal resources) and renewable sources (e.g., forestry and energy sources such as hydro, wind, and solar). Forest covers almost half of Canada's landscape. Canada has 10 percent of the world's forest cover, 25 percent of the world's natural forest, 30 percent of the world's boreal forest and 20 percent of the world's rainforest. Canada produces more than 60 minerals and metals, and ranks first in the world production of potash and uranium. It ranks in the top five countries for more than a dozen minerals and metals, and Canada is also rapidly emerging as a major diamond producer.

3.1.2 Economic Contribution

Over the past century, Canada's natural resources sector has made a significant and sustained contribution to the Canadian economy (Report of the Standing Committee on Industry, 2000). The natural resources sector and allied sectors is a cornerstone of Canada's economy. Canada's natural resources sector operates in a competitive, national and international environment and it must compete for investment dollars with other sectors within Canada and internationally (see, for example, Committee on the Competitiveness of the Resources Industries, 1993). In 2005, the natural resources sector accounted for 13 percent of gross domestic product (GDP), \$67B in investments or 25 percent of Canada's total, and 46 percent of total exports (NRCan, 2006a). The sector is capital intensive and productivity in the sector exceeds that of the economy on the whole (CBOC, 2001c; Figure A3, Appendix 3). The sector accounted for almost \$166 B in exports and contributed significantly towards Canada's positive trade balance. Without the trade surplus of \$90B for natural resources, Canada would have had an overall trade deficit of \$35B.

The natural resources sector also accounts for about one million direct jobs, which are spread throughout communities of all sizes in all regions of the country. Over 600 communities in Canada depend directly on the natural resources sector. Furthermore, natural resource activities are often the main economic driver for many rural and remote economies, and they offer significant opportunities for Aboriginal involvement.

3.2 Canada's Energy Sector

The availability of different sources of energy at reasonable cost has been a key factor in the attainment of a high standard of living in Canada. This advantage has led to the development of industries having particularly strong demands for energy. Canada's energy resources have helped Canada to develop a strong industrial economy and given Canada a competitive edge over other countries (NRCan, 2000). Canada produces energy from diverse sources, including fossil fuels (oil gas, and coal), hydro electricity, and nuclear power. Significant interest exists in alternate energy sources, which include hydraulic, solar, wind, biomass and other innovative technologies such as the fuel cells. Canada's energy resources have also helped Canada deal with the economic disadvantages of small domestic markets, long distances, rugged geography, and a relatively harsh climate. Of particular relevance is the oil and gas industry, which is examined below.

3.3 Upstream Petroleum Sector

3.3.1 Overview

A key part of Canada's energy sector is the upstream petroleum sector. The oil and gas sector is a very important part of the Canadian economy, as reflected by its contributions to Canada's GDP, investment, trade, regional development, and employment. Crude oil and natural gas account for two thirds of Canada's energy production. The petroleum industry is usually discussed in terms of upstream and downstream operations. The upstream petroleum industry discovers, produces, and processes oil and natural gas (Petroleum Communications Foundation, 2001). Exploration and development activities refer to all the upstream activities that are required to find new oil and natural gas resources and develop them to the point where they are ready to be refined. Exploration involves the search for petroleum, including seismic surveys and drilling. Production describes the steps of getting petroleum out of the ground. The upstream sector includes hundreds of companies directly or indirectly involved in exploration and production and associated businesses, such as seismic and drilling contractors, service rig operators, engineering firms and various scientific, technical, service, and supply companies. While companies operate across the country, the industry is concentrated in Western Canada, in particular Alberta.

3.3.2 Exploration and Development Activity

Exploration and development efforts of the industry are presented in terms of exploration and development wells (see Figure 3.1). Seismic (geological and geophysical) activity is part of

exploration activity. Oil and gas producers acquire services from specialty service companies who own their rigs. The oil and gas companies are purchasing the services for the embodied technology.

Figure 3.1: Exploration and Development Activity

Source: Data were taken from the Canadian Association of Petroleum Producers, *Handbook*, 2006.

Oil and gas expenditures have been increasing at a rapid pace to bring on additional oil and gas production. Figure 3.1 shows that drilling activity has been increasing significantly over the past several years. In 2005, 25,000 oil and gas wells were drilled; this was 12 percent above the record set in 2004. Since 1998, drilling activity has increased, on average, at 8 percent each year.

Gas directed wells accounted for about 80 percent of well completions and oil accounted for remaining 20 percent. Drilling rigs in operation averaged about 490 per month in 2005 and 460 in 2004; this reflects very high rig utilization rates. On a provincial basis, Alberta accounts for about 78 percent of the wells drilled and Saskatchewan 16 percent.

3.3.3 Crude Oil Production

Table 3.1 provides estimates of Canada's historical crude oil production and long term projections.

Table 3.1

Canadian Crude Oil Production (Thousands of Barrels Per Day)

	2000	2005	2010	2020
Conventional Light Oil (includes East Coast and Pentanes Plus Supplies)	1,002	1042	860	603
Synthetic Oil (upgraded Bitumen)	315.6	552	1,200	1,821
Total Light	1,317.6	1,594	2,060	2,424
Conventional Heavy	560	476	515	360
Bitumen	280	438	800	1,100
Total Heavy	840	914	1,315	1,460
Total Crude Oil and Equivalent	2,157.6	2,508	3,375	3,884

Source: Historical numbers are taken from the NEB, 2006a, Table 3, p. 19 and Canadian Association of Petroleum Producers, Statistical Handbook (2006a). Numbers exclude natural gas liquids (Ethane, Propane, and Butane natural gas liquids of 590 thousand barrels per day in 2005) and have been rounded in conversion from cubic metres to barrels per day. Forecast numbers are taken from NRCan (2006b, p.136). Conventional light oil in 2000 includes 145 thousand barrels per day of production from the east coast in 2005 and 305 thousand barrels per day.

Canada's crude oil production is expected to increase from 2,158 thousand barrels per day to 3,884 in 2020 according to NRCan forecasts (NRCan, 2006). In 2005, Canada's crude oil production was 2,508 thousand barrels per day (mb/d). Most of Canada's crude oil production (88 percent) comes from western Canada, with the remainder from eastern

Canada. Approximately 64 percent of Canada's oil supply is light oil; the remaining 36 percent is heavy oil including bitumen. Synthetic oil – upgraded bitumen – accounts for an increasing share of Canada's light oil supply. In 2000, synthetic oil supply accounted for 24 percent of Canada's light oil and in 2005, 34 percent. Similarly, bitumen accounted for 33 percent of Canada's heavy oil supply in 2000 and is now accounting for 48 percent of the heavy oil supply. The NEB (2006) notes that oil production outstripped the reserves additions by 25 percent over the period from 2000 to 2004 period. Reserves added were 329.6 million cubic metres as compared to the production of 412.4 million cubic metres.

Canada's oil supply is projected to increase but a larger share is expected to come from the more expensive non-conventional sources such as bitumen and synthetic oil. As well, the ratio of heavy oil to light oil is increasing. Canada uses very little heavy oil for domestic consumption and must therefore export the excess supply, mainly to the U.S. where it is upgraded. The greater the supply of heavy oil, the greater the differential of the price of light to heavy oil (i.e., producers receive less for heavy oil when too much of it is produced). Hence, greater interest exists in producing light oil. A significant amount of Canada's oil is expected to come from bitumen and synthetic oil. The Canadian Association of Petroleum Producers (2006b) is projecting production from oil sands to be substantially higher than that of NRCan. It should be noted that oil and gas supply forecasts vary from one institution to another (e.g., NRCan, NEB, the Canadian Association of Petroleum Producers) mainly because of the number of underlying assumptions. Persaud and Kumar (2001) note that supply forecasts are based on several assumptions including prices, government policy, cash flow, reserves, finding rates, oil and gas directed investments, and major project developments.

3.3.4 Natural Gas Production

Natural gas production in 2005, was 6 trillion cubic feet; it has been fairly stable over the past five years. While Canada's oil supply comprises several sources, natural gas comes mainly from Western Canada, with a small amount from eastern Canada. Alberta and British Columbia together accounted for 93 percent of Canada's production with Saskatchewan accounting for 4 percent and the Sable Island Project off Nova Scotia 2 percent. The Northwest Territories and Ontario accounted for the remaining one percent of production. As with oil, natural gas production outstripped the reserves additions but only by 10 percent as compared to 25 percent for oil. In 2005, the upstream oil and gas sector accounted for \$27.9B, or 38 percent of the total energy sector GDP of \$75B. Alberta accounted for 75 percent of Canada's total upstream petroleum production.

In order to obtain a sense of the size of the upstream oil and gas sector relative to the energy sector, a common base of energy output is used in terms of peta-joules. In 2005, Canada's energy production was 17,313 peta-joules¹⁴ (NEB, 2006a). Petroleum and natural gas accounted for 36 percent and 38 percent respectively for a total of 76 percent of Canada's energy production. Hydroelectricity, nuclear, coal, renewables, and other sources accounted for the remaining 26 percent of Canada's energy production.. Fossil fuels – such as petroleum, natural gas, coal resources – are considered as non-renewable resources because they took millions of years to form naturally and cannot be replaced as fast as they are consumed. Consumption leads to depletion and, hence, to an increase in supply costs. On

the other hand, forestry is considered as a renewable resource – it grows naturally and, in theory, can be used sustainably without depleting existing stocks. Similarly, energy sources such as wind and solar are renewable, but currently they do not play a dominant role in Canada's energy demand and supply mix.

3.4 Canada's Crude Oil and Natural Gas Reserves

Reserves and more particularly established reserves of crude oil, natural gas, and associated liquids are considered to be commercially recoverable under existing market conditions, government regulations, and existing practices. Reserves have certain special features – they have not yet been produced; being underground, they cannot be accurately estimated and are subject to uncertainty; they cannot be produced at a single point in time (it takes years to deplete a field and hence their sales price is difficult to predict); and they are the wealth of the upstream companies (see for example, Conaway, 1999; NEB, 2006; AEUB, 2005).

As can be seen from Table 3.4 Canada's crude oil reserves are immense but only a small part is in conventional areas. Further, about 25 percent of conventional oil reserves are in offshore areas (North West Territories, Nunavut) and the Yukon, Cohasset and Panuke off Nova Scotia; and Hibernia, Terra Nova and White Rose, off Newfoundland. Almost 98 percent of Canada's oil reserves are in oil sands. The existence and importance of Canada's vast bitumen resource base continues to attract attention from multinationals, integrated oil

¹⁴ Consumption is usually expressed as a common base (e.g., peta-joules, tonnes) to derive demand for each fuel type. On a world scale, in 2000, oil accounted for 40 percent of energy consumption, gas 25 percent, hydro-electricity, 3 percent and nuclear energy 7 percent.

companies, and national oil companies seeking to participate in oil sands development.

Reserves to production ratio for Canada excluding oil sands are about 8 years.

Table 3.2

**Canada's Established Crude Oil Reserves at December 31st, 2004
(Millions of Barrels)**

	Initial Reserves	Remaining Reserves
Conventional Crude Oil	23,340	2, 932
Conventional Areas (Western Provinces and Ontario)		
Frontier (including North West Territories; Cohasset and Panuke, Nova Scotia; and Hibernia, Terra Nova and White Rose, Newfoundland)	1,888	1 100
Total Conventional oil reserves in Canada	25,228	4,032
Reserves/Production (R/P) ratio in number of years (using current production)	50	8
Oil Sands		
- Oil Sands Upgraded (surface mining)	35,217	32,067
- Oil Sands Bitumen	143,652	142,191
Total Oil sands	178,869	174,258
Total established oil reserves Canada	204, 097	178,290
R/P Ratio in number of years (using current production)	226	197

Source: National Energy Board (NEB), 2006a; NEB, 2006b; Alberta Energy Utility Board (AEUB), 2005.

When oil sands reserves are included, this ratio increases to close to 200 years. This ratio is even much higher if resources rather than established reserves are considered. These are established reserves estimates. However, what is of even greater interest is resource potential; this would add significantly to Canada's ability as an oil producer.

A small percentage of Canada's oil and gas resources are low-cost resources. Canada has vast high-cost oil sands (very heavy oil) and offshore supplies. Only a small percentage of reserves can be produced with the current technology and at prevailing prices; these are called proven reserves (conventional reserves). Canada's low cost reserves are located in conventional areas, such as Alberta, Saskatchewan, and British Columbia. To find and develop new conventional resources is becoming more difficult and expensive. This requires the application of advanced technology. On a world scale, Canada, like the United States, is a high-cost oil producer where resources are becoming more difficult to find. Most Persian Gulf countries can produce oil in the range of \$5 per barrel.

Table 3.2 shows Canada's established natural gas reserves. Canada has about 61 trillion cubic feet (Tcf) of established reserves (lower-cost supplies) which are located mainly in Western Canada. These reserves are distinct from higher-cost gas resources – undiscovered resources which total over 350 Tcf (see Table AP 2.3, in Appendix 2).

Canada is well endowed with oil and gas reserves in frontier regions: offshore Newfoundland, Nova Scotia, British Columbia, and Northern Canada. Three major projects are the world renowned Hibernia, Terra Nova, and White Rose oil projects; offshore Newfoundland; and the Sable gas project offshore Nova Scotia. Ben Nevis is expected to come on stream in 2011.

Table 3.3

**Canada's Established Natural Gas Reserves as
Of December 31st. 2004 -Trillions of Cubic Feet**

	Initial Reserves	Remaining
Conventional Areas (Alberta, BC, Saskatchewan, Manitoba, & Ontario)	196.8	52.9
Frontier		
- NWT, Nunavut & Yukon	1.1	0.5
- Nova Scotia	1.9	1.1
Total Frontier	3.0	1.6
Total Canada	199.8	54.5
Remaining Reserves/Production (R/P) ratio in number of years (using current production)	N/A	8.8

Source: National Energy Board (NEB), 2006a; NEB, 2006b; NRCan 2006d.

The sheer size and the strategic importance of Canada's oil sands require special attention. A significant amount of the world's natural bitumen reserves are located in Canada and the United States. Figure AP1. F3 in Appendix 1 shows the location of the oil sands project in Canada. Oil sands production forecasts are continuously being revised to reflect new projects and project expansions. Table 3 A.2 at the end of this chapter shows recent announcements of oil sands developments. The oil sands reserve is upgraded into synthetic oil at the Suncor Energy and Syncrude Canada plants, or produced and exported in the form of bitumen. The Shell Scotsford refinery in Alberta and the Husky (Lloyd) in Lloydminster at the Alberta Saskatchewan border are also major refiners of bitumen and heavy oil. Canada's reserves are believed to be of better quality and are more commercially attractive than the U.S. shale oil deposits and the Orinoco Deposits in Venezuela. This reserve deposit is the third largest oil resource basin in the world, after the Persian Gulf and Venezuela (see,

for example, Alberta Chamber of Resources, 2004; AEUB, 2005). This section will focus on Canadian operations, since commercial production takes place here and it is becoming increasingly important.

Canada's oil sands reserves are located in three main geographic areas in Alberta: Athabasca, Cold Lake, and Peace River. Of Alberta's vast resources of oil sands of 1.7 trillion barrels of oil in place, 178 billion barrels are considered established reserves yet a larger quantity is considered recoverable. The two methods of extracting bitumen from oil sands are surface mining and in situ (in place) extraction. Technology advances in both surface mining and in-situ recovery have occurred over the past several years and the SAGD in-situ process, analysed in this thesis, is one such development (Figure AP1.F2 in Appendix 1 shows a three-dimensional display of the SAGD process). The reserves that are mineable from the surface lie under less than 75 metres of overburden. Overburden is a layer of sand, gravel, and shale between the surface and the underlying oil sand. This layer must be removed before the oil sands can be mined by surface extraction methods. The sands containing the oil are then processed and upgraded to refiner specifications.

- In situ recovery, unlike surface mining, refers to methods to extract the bitumen without having to remove the overburden and then processing the oil sands. In-situ operations use thermal techniques to heat the oil sands while still in the ground and liquefy the oil in order to separate it from the oil sands. There is a soaking period after the steam is injected into the reservoir. Wells are used to pump the heated oil (and water) to the surface. About 20 to 25 percent of the oil in place is recovered

(Asgarpour, 2004). The reserves of bitumen suitable for in situ recovery methods are almost 10 times the size of those accessible by surface mining. The largest of the commercial in situ projects in Alberta is Imperial Oil's Cold Lake facility. Construction of this project, which uses cyclic steam stimulation, began in 1983.

3.5 Canada's Position in the World

Figure 3.2 shows the top countries in terms of reserves.

Figure 3.2: Top Ten Countries in the World in Terms of Crude Oil Reserves

Note (*): Canada's crude oil reserve estimates include oil sands reserves. Canada's conventional reserves are about four billion barrels as compared to the U.S.'s of 21 billion barrels.

Source: Information extracted from the *Oil and Gas Journal*, 2005. Volume 103, No.47.

Canada ranks among the top in terms of world's reserves (second only to Saudi Arabia), but these estimates include the oil sands reserves, which are considered higher cost supplies. Table AP1.1 in Appendix 1 shows the world's crude oil production by major producers and AP2.1 shows the countries with the most oil reserves. Canada produces close to 4 percent of

the world oil supply and Canada's petroleum sector is strategic to the U.S. Canada ranks as the largest exporter of oil to the U.S. World energy demand is expected to increase by 53 percent between 2004 to 2030 or at an average rate of 1.6 percent per year (IEA, 2006a). The IEA expects 70 percent of the increase to come from developing countries. Fossil fuel use is expected to account predominantly for increases in energy demand, with oil set to maintain its share. The transportation sector is expected to account for the largest share of final oil consumption (IEA, 2006a). Canada's demand is also expected to grow at a robust rate. The strong demand forecast suggests that there will be strong future demands for Canadian petroleum.

3.6 Energy Security

Oil is viewed as a strategic commodity, which involves it in politics and conflict on a local, national, regional, and global basis (Mitchell, *et al.*, 1996; Parra, 2004; Stevens, 2005). In 2003, 47 percent of world oil exports came from the Middle East and North Africa. The instability of this region is a source of concern and is forcing governments to develop policy alternatives – conserving, developing alternative technologies, increasing domestic supplies, diversifying sources of oil imports, and building up strategic stocks. The rapid development of major economies, such as China and India, is expected to result in substantial and growing energy demand. Recently, China has overtaken Japan as the world's second largest consumer of automobiles, and the view seems to be that China's policy is to change a largely bicycle culture to a car culture.

Energy security is a major part of energy policy of the U.S. and other OECD countries (IEA, 1997). The development of oil and gas and other sources of energy, the diversification of import sources, and the investment in energy efficiency figure prominently in U.S. energy policy. Anderson and Newell (2004) and IEA (2006b), maintain that interest in energy efficiency improvements has been re-invigorated by concerns ranging from the environmental effects such as climate change due to carbon emissions or environmental damage caused by pollutants in addition to energy price volatility and national security. The IEA (2003) notes that energy security continued to be a key concern of policy makers in 2003, influenced by the current volatility in oil markets. The wars in Afghanistan, Iraq, and Lebanon have exacerbated concerns about energy security. In the current environment of insecurity and oil supply disruptions, assurance of stable sources of supplies is deemed crucial. The sector is strategic for U.S. security, given its dependence on petroleum to meet its energy requirements. An understanding of the application of technology, with respect to the development of domestic oil and gas resources, can provide insights into key factors for ensuring secure, reasonably priced sources of energy. Using renewable sources of energy, diversifying import sources and investing in energy efficiency, and providing an appropriate regulatory environment are also seen as important for improving energy security.

3.7 Global Prices and Competitive Markets

Investment decisions in the petroleum industry are often difficult due to the significant uncertainty associated with forecasting the production and economic performance of oil and gas fields (Holmes, *et al.*, 2006). One of the biggest uncertainties with respect to economics

is oil price. Companies have sought to address this through developing price scenarios such as low-price case, a reference case price and a high-price case. Government departments and agencies have used similar approaches to forecast oil and gas production (e.g., US/ Department of Energy (DOE)/Energy Information Administration (EIA), IEA, NEB, and NRCan). But considering the high cost of developing full-blown multiple scenarios, a base case or most likely scenario is employed with several sensitivity analyses (“what ifs” around the reference case).

3.7.1 Crude Oil Markets

Knowledge of the behaviour of crude oil prices and natural gas prices is key to understanding the environment in which companies operate. Oil prices remain a key variable in determining the health of economies. The rapid increase in prices over recent years has been driven largely by geopolitics and concerns of security of supply. For energy producers, the prices that are important are posted prices for oil and plant-gate prices for natural gas. The behaviour of oil and gas prices is a key determinant of oil and gas supply and demand behaviour (Persaud and Kumar, 2001; Krichene, 2002; US/DOE/EIA 2007b). The most popular reference crude oil in North America for quoting crude oil prices is West Texas Intermediate (WTI) at Cushing Oklahoma. This crude oil has a low density and low sulphur content. Saudi Arabian Light, the OPEC basket of eight vintages of crude oil and North Sea Brent crude are also reference crude types. The wellhead prices received by the producer are adjusted to reflect quality differential with the reference crude and the transportation cost to the basing point (Cushing, Oklahoma gas prices.). Natural gas prices at Henry Hub, in the

U.S. Gulf Coast, are a useful indicator of Canadian natural gas prices and a good indicator of the supply / demand market conditions (U.S. DOE/EIA, 2007a).

**Figure 3.3 Crude Oil Prices - \$US/bbl
West Texas Intermediate (WTI)**

Source: Data taken from the BP Statistical Review of World Energy 2006.

Figure 3.3 shows the trend in crude oil prices since 1973, as well as the major political influence on oil prices. A well known fact of the resources sector is that commodity prices (including oil and gas prices) are cyclical and volatile. Schulam and Garret, Jr. (2005) note that quite often volatility in world crude prices is as much a function of political instability as it is the underlying economics of supply and demand.

Prior to 1973, world crude oil prices exhibited remarkable long-term stability (Adelman, 1979; Adelman 2002; Krichene, 2002). Prices averaged U.S.\$1.40/barrel (bbl). Nouredine and Crucian (2002) note that prices have exhibited remarkable long-term stability over the

period of 1918-1973. Since then, prices have been volatile due to a number of major events (Stevens, 2005; Holmes, *et al.*, 2006). The first oil shock took place in 1973 after the Arab oil embargo, which caused oil prices to triple and brought profound economic disruption around the world in the ensuing years (Martin, *et al.*, 1996; Adelman, 2002). Oil prices rose to \$3.20/barrel in 1973. The Arab oil embargo was followed by a number of destabilizing events in the Middle East, these included the Iran Revolution, the Iran/Iraq War and the Gulf War, the Asian economic crisis in 1998 and 1999 and the wars in Afghanistan and Iraq. Prices have more than doubled since 2003 from U.S. \$31/bbl to an average U.S. \$66 in 2006. Most recently, in August 2007, prices have reached over U.S. \$70/bbl.

As prices rise, profitability increases and firms are inclined to increase production and go after higher cost supplies. On the other hand, as prices decline due to excess supply, profit margins are squeezed and companies are more motivated to reduce costs. At any fixed price, a rise in the Canadian dollar also reduces the price for oil and natural gas received by the Canadian producer since oil is priced in U.S.\$\$. This has implications for profitability. The current environment of relatively high prices, however, has offset the appreciation of the Canadian dollar over recent years. Another way to look at oil prices is in terms of nominal real terms. Crude oil prices during the past four decades can be summarized as follows:

	<u>Nominal \$U.S./bbl</u>	<u>Real (\$U.S. 2006/bbl)</u>
1970s	10.00	35.40
1980s	26.35	53.15
1990s	19.15	26.05
2000-2006	39.65	42.40

These trends show that prices are the highest in this decade in nominal terms, but in real terms, the 1980s was the period of the highest prices. OPEC, and particularly Saudi Arabia, has most of the world's excess capacity. This provides them with continued influence on oil prices.

3.7.2 Natural Gas Markets

Unlike oil, the prices faced by natural gas producers are determined in North America and are not subject to geo-political situations *per se*. The U.S. and Canadian natural markets are highly integrated (U.S./DOE/EIA, 2007a). Canada is a major natural gas supplier to the U.S. with the Midwest accounting for 48 percent of imports from Canada, the U.S. North East 28 percent, and the West coast 24 percent. In 2005, Canada produced 6 Tcf and exported 3.7 Tcf to the U.S. Approximately 96 percent of the exports flowed through 9 major export points; with the majority of the exports went through the Kingsgate, Monchy, Elmore, and Emerson border points (NRCan, 2006d). Canada also imported .38 Tcf from the U.S. In 2005, the U.S. also exported .3 Tcf of natural gas to Mexico (9 billion cubic feet). Mexico has a substantial amount of gas reserves, and long-term possibilities exist for that country to supply the U.S. markets. However, significant capital expenditures would be required to build pipelines to supply the U.S. markets, which is not likely to happen in the near to medium term. Thus, the growing U.S. market is expected to provide great market opportunities for Canadian natural gas.

Oil sands operations (mining and in-situ) require significant amounts of natural gas. Since 2000, natural gas use has increased close to 90 percent. In 2005, natural gas demand at oil sands operations was approximately 250 billion cubic feet, or 10 percent greater than the yearly demand of Saskatchewan.

In recent years, natural gas markets have become highly competitive due to improved pipeline accessibility and the greater use of storage capacity. Increased fuel to fuel competition among oil, gas and electricity and increased flexibility in terms of fuel switching for industrial use are factors that have influenced natural gas prices. Another influence of natural gas prices has been natural disasters, such as Hurricanes Katrina and Rita, which at their peak caused a substantial shut down of more than 90 percent of production. This resulted in price spikes and market disruptions. It is important to look at natural gas prices from a North American perspective. The two key North American natural gas price hubs are the Intra-Alberta Market in Alberta (AECO) and Henry Hub in Louisiana.

**Figure 3.4: Trend in North American
Natural Gas Prices – Henry Hub
(\$U.S./MCF (NYMEX))**

Figure 3.4 shows that natural gas prices have increased from 1991 until 2005. Prices declined in 2006 reflecting an over supply in natural gas. Table AP 2.2 in Appendix 2 shows natural gas prices in both \$U.S. and Canadian dollars over the same period. In 2005, the natural gas spot prices at Henry Hub, in the U.S. Gulf Coast were close to \$8.00/ per thousand cubic feet (Mcf). The U.S. DOE projects prices to decline to \$5.76 /Mcf by 2010 and \$5.22/Mcf by 2020 (U.S./DOE/EIA, 2007b, p. 159). NRCan (2006b) also calls for prices to decline over the long term. One barrel of crude oil is equal to approximately 6 MMBtu of natural gas and the industry often speaks of a 6 to one price ratio. Although natural gas has tracked this ratio, recently the ratio has been greater than 12 due to the significant increase in crude oil prices. Elevated storage levels have helped to keep the price

of gas down. Since oil and gas are not complete substitutes, one cannot expect that the ratio will be in equilibrium.

Only a relatively small amount of the world natural gas demand is satisfied through liquefied natural gas (LNG) trade. In recent years, however, there has been increased interest in the U.S. and Canada towards LNG. Of the total U.S. demand of 21.9 Tcf of natural gas in 2007, LNG was only .57 Tcf or 2.6 percent (U.S. DOE/EIA, 2007b). LNG use, however is projected to increase to 12 percent of natural gas demand by 2015. Canada is not an international player in LNG but it could become an important North American player. To capitalize on energy market conditions, Canada will have to make significant investments in new transportation and storage infrastructure on its coasts. Currently, eight LNG projects are being planned or already being constructed: three in Nova Scotia, two in Quebec, one in New Brunswick and two in British Columbia. LNG projects in eastern Canada are likely to face competition from similar proposals in the North East U.S (CBOC, 2007).

3.7.3 Pipelines

Pipelines are a vital link in the oil supply chain of the upstream petroleum sector. When crude oil is produced it is collected through a network of gathering lines and then moved through feeder lines into the main trunk lines. The main trunk lines are the connection between the upstream producer and the downstream refiner. Although crude oil could be transported via truck or rail, pipelines are the most practical, reliable, and economic mode of transporting crude within Canada and for export to the United States (NEB, 2006a). Most feeder pipelines in Alberta, including those that transport synthetic crude oil (SCO) and

blended bitumen, deliver crude oil to two hubs located in Edmonton and Hardisty, Alberta. From these locations, crude oil can be transported in segregated batches to delivery points in Canada and the U.S.

Natural gas is gathered from the field in gas pipelines and then shipped to processing stations. From these plants, natural gas is shipped through various networks for domestic use, export, and storage. Unlike oil, which can be stored in surface facilities, natural gas is stored in reservoirs (usually using depleted reservoirs) until it is ready to be consumed. Most natural gas for export goes through nine export points to the U.S (NRCan, 2006; US/DOE/EIA, 2007a). The bulk of the natural gas consumption, during any given year, takes place in the cold winter months in both the U.S. and Canada. Given the growth of storage capacity in recent years, throughputs in pipelines are still kept high during the summer so natural gas can be shipped close to markets for storage to augment winter supplies.

3.7.4. Mackenzie Valley Pipeline

The Mackenzie Valley Pipeline, if built, would transport natural gas from the Mackenzie Delta in the northern Northwest Territories more than 1200 kms south to an inter-tie at Alberta's northwestern border. Canadian oil and gas companies – Imperial Oil, Conoco Phillips, Canada (North) Limited, Shell Canada, Exxon Mobil and the Aboriginal Pipeline Group (APG), a group representing the aboriginal peoples of the Northwest Territories – are partners in the proposed project. The original goal was to have natural gas flowing from the

north to markets in the south. The main Mackenzie Valley pipeline would connect to existing natural gas markets in Northwestern Alberta. The proposed project was expected to cost \$7B; a recent estimate is in the range of \$16B (CBOC, 2007). The project requires the cooperation of many different companies, communities, settlements, regulator agencies, and governments. The proposed project crosses four aboriginal regions in Canada's Northwest Territories (NWT). Natural gas was discovered there in the 1970s – the project has been talked about for a long time.

In the 1970s, a federal government inquiry by Mr. Justice Thomas R. Berger into the proposed development resulted in the recommendation to place a 10-year moratorium on the project while the First Nations land claims were settled. Although Justice Berger recognized, however, that the project was inevitable, development was not right at that time. The project has had several delays and the CBOC (2007) notes that if the project is delayed again, it may be a generation again before it comes up. The project requires approval from federal, territorial, and provincial settlement area regulator authorities responsible for assessing and regulating energy developments.

3.8 Sustainable Development

Sustainable development was brought to the attention of the world in 1987 by the Brundtland Commission (World Commission on Environment and Development, 1987). The final report from the WCED (1987) is entitled *Our Common Future*. Since then, the concept has gained immense popularity among government leaders, academic institutions, industry, and

environmentalists alike in both industrialized and developing countries. The report emphasized the fact that environmental threats are a reality and disasters are occurring on regular basis. It examined the critical environment and development problems and discussed proposals to address them. Essentially, the recommendation was to combine ecology and economy so that those causing environmental damage assume responsibility for the damage, while acknowledging the need for continued development. This concept, referred to as sustainable development, is defined by the WCED as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Canada is well endowed with natural resources and strongly subscribes to the concept of sustainable development. We must note that sustainable development is not considered a fixed state. In the natural resources sector sustainable development is seen as a constantly evolving process of identifying and seizing new opportunities to improve environmental and economic performances to maximize social and economic benefits. The application of innovative new ideas and technologies is important for yielding economic, environmental, health and social benefits for all regions – benefits that lead to a higher quality of life for Canadians. Legislation is considered a very important factor in bringing about the change in values required to ensure adequate resources for future generations (WCED, 1987).

The magnitude and diversity of Canada's natural resources are truly astonishing. Not only does our landscape supply us with the raw resources that are the foundation of a significant portion of our economic activity, it also provides essential ecological services such as clean air and water which are essential to our economy and quality of life (NRCan, 2006c).

Energy is necessary for survival. The role of energy, in terms of economic growth and the adverse environmental effects often associated with its use, is well known. The economy, energy, and the environment are so intertwined that one cannot be changed without regard for the other. Future economic development depends crucially on the long-term availability of energy in increasing quantities from sources that are dependable, safe, and environmentally sound. Energy efficiency measures to reduce energy intensity are considered crucial for sustainable development.

Provinces also are placing great emphasis on innovation productivity and the environment as reflected in recent provincial budgets. For example, Quebec's 2007-2008 budget called for increased investment in productivity, development of a \$1.2B climate change action plan, and a reiteration of a green energy policy tabled in May 2006 that pledges more than \$6B over the next ten years. British Columbia outlined ambitious climate change and energy initiatives in its recent budget of \$103 millions over four years and an ambitious target to reduce greenhouse gas emissions – 33 percent by 2020.

3.9 Exploration Uncertainty

Firms face significant uncertainty in exploring for crude oil and natural gas. Firms, therefore, carry out extensive geological and geophysical analyses before undertaking drilling, in order to improve their chances of finding new deposits of oil and natural gas. A key function of the exploration geologist is to locate the spot on a map that covers a huge area of the earth's surface where a wildcat well is to be drilled to evaluate the prospect of

finding petroleum (Conaway, 1999). The hole is only about 8 inches in diameter and it is very easy to miss a target and a single dry hole wildcat often condemns the entire project with millions of dollars lost. The average success ratio is in the ballpark of 1:8 in Canada. Given the high capital costs related to exploration, firms are continuously seeking to improve their success ratios. After a prospect is abandoned by the original operator, it is not unusual for a competitor to pick up and drill the discovery well. A more serious loss occurs when incorrect placement caused a competitor to make a new field discovery that the original operator missed. Firms are always interested in targeting oil and gas deposits although a firm may be more interested in one product than the other at a specific time. For instance a firm may wish to tie in additional supplies to an existing line and would be looking for, say, only oil or in other cases just natural gas. Figure AP1 F.1 in Appendix 1 shows a vertical oil well in production in a typical reservoir.

Discussions on the role of the resource base in the literature is interesting because it shows the changes over time and its ultimate development (e.g., Hotelling, 1931; Dasgupta and Heal, 1979; Kneese and Sweeny, 1993; Fisher, 1994; Adelman and Lynch, 1997; Cleland and Kaufmann, 1997). A key point in the literature is that resource estimates do not take adequate account of technological developments. To simply extrapolate supply from a given reserve base would, therefore, underestimate supply unless sufficient allowance is made for the technological impact.¹⁵ Emerson (1997) argues that it is time to abandon Hotelling's

¹⁵ Adelman and Lynch (1997) note that ultimate recoverable oil potential in the US was estimated at 170 billion barrels in 1974. Production to date has already exceeded this amount, proven reserves are 20 billion barrels, and discoveries continue to be made. A parallel story exists for natural gas.

principle (1931) assumption of fixed stock of oil in favour of a more subtle characterization of oil reserves as a flow – a flow that is dependent on continual adaptation and innovation to keep replacement costs below price – and that this will lead to continued investment.¹⁶

3.10 Energy and the Environment

There are several environmental problems associated with the production and consumption of energy. Exploration, production, and transportation activity impact the natural environment in different ways. Tens of thousands of wells and thousands of kilometres of pipeline and roads have a large cumulative effect over a wide area of the landscape. Major industrial operations – such as oil sand mines, and gas processing plants – have major effects on relatively small areas. Offshore development poses threats to marine life and birds. Low water temperatures and frequent storms also make it difficult to clean up oil spills. Similarly, accidents can cause loss of lives of workers at work sites. Every year, workers have accidents and lose their lives at drilling and production sites. The loss of the Ocean Ranger and its crew is a prime example of the dangers associated with the industry. Further, low water temperatures also slow down the processes of evaporation and bacterial action that eventually break down oil. The production of oil sands results in large amounts of waste that are stored in tailings ponds. Tailing ponds store a slurry of water, clay, sand, and residual

¹⁶ The theoretical paradigm that has influenced our thinking about the petroleum industry for some time is the *Hotelling Principle* of resource scarcity which was foreshadowed by Malthus' contention that the more the world consumes its resources, the less it has left (Emerson, 1997). Hotelling's (1931) fundamental argument was that the future price of oil is an inclining curve, largely because the volume of oil in the ground is finite.

bitumen from production until solids settle and reclamation can take place. Oil sands production, which is expected to increase, requires the use of substantial quantities of water, and energy. Production of oil sands generates a high level of CO₂ emissions primarily from the use of fossil energy to separate the oil from the sand.

The “greenhouse effect” is associated with the emission of particular gases, the main contributor being CO₂ emissions due mainly to the production and consumption of fossil fuel (oil, natural gas and coal). Energy production and its use account for 80 percent of greenhouse gas emissions. Scientists warn that the continued increase in greenhouse gas concentration could cause irreversible global warming and climate change, entailing severe detrimental economic and ecological effects. The impact of these gases is expected to result in overall global warming, which could, over the next century or decades, raise sea levels and produce floods, thereby threatening coastal settlements. It could also produce more heat waves and droughts and shift climate zones so rapidly that many plant and animal species could not adjust quickly enough to survive. The effect of increasing atmospheric CO₂ concentration on global warming is considered as one of the most important environmental issues facing society (White, *et al.*, 2005). Although there continues to be some debate on the extent of global warming, the Intergovernmental Panel on Climate Change (IPCC), under the auspices of the World Meteorological Organization and the U.N. Environment Program is predicting that the average temperature of the earth would rise by about 0.3 percent each decade over the next century. Although relatively small, this is believed to be a significantly faster rate of increase than has been attributed to natural causes over the past 10,000 years.

This issue is being addressed internationally through the formation of organizations such as the United Nations Framework Convention on Climate Change (UNFFCC) and the IPCC. To stabilize atmospheric levels of greenhouse gas emissions while minimizing the world economic impact, four options are being explored, which project the use of: i) less carbon intensive fuels; ii) more energy-efficient methods; iii) energy conservation; and iv) carbon sequestration. Storage of captured CO₂ in coal seams in the U.S. and saline aquifers has also been receiving considerable attention (White, *et. al.*, 2005). The U.S. DOE (2004, p.3) notes that: “as much as 90 percent of the original oil remains un-produced in many U.S. reservoirs.” The government is working with provincial governments, industry partners, and experts from around the world on a large scale monitoring and storage of CO₂ project in an enhanced oil recovery operation (EOR) near Weyburn Saskatchewan. The project has completed its first phase objectives, which was to evaluate the large-scale demonstration of a CO₂ EOR application and tracking for understanding CO₂ movement in a reservoir. The new focus of injecting CO₂ is to reduce greenhouse gas emissions as well as improving enhanced oil recovery.

While the government has demonstrated a commitment to sustainable development and has taken several opportunities to support this stand, the question arises of how commitment is translated into action. What policies must be developed to support the concept of sustainability without compromising economic growth? How can the government assume responsibility for global issues while ensuring fairness to those affected locally?

A significant concern pertaining to energy and the environment relates to greenhouse gases and the impact on global warming. This issue has attracted attention for the last 25 years and intensified in recent years. The combustion of fossil fuels results in emissions of all three of the major greenhouse gases: CO₂, nitrous oxide (N₂O) and methane (CH₄). CO₂, which has received the most attention, represent the largest share of global greenhouse gas emissions and most of it comes from energy consumption.

How firms balance competition and contribute to the community and the broader society in which they operate is always important. Canadians want to share equitably in the benefits of economic progress to ensure a high quality of life in communities where these companies operate (Government of Canada, 2003). Further, both domestic and global consumers want assurance that the firm they purchase from is a good corporate citizen. Stakeholders – such as investors, regulators, municipalities, and non-governmental organizations – are looking beyond a company's economic performance to see if it conducts business in an ethical and socially responsible manner.

The *Kyoto Protocol* called for limiting greenhouse gas emissions. This international agreement was reached in 1997 in Kyoto to address the problems of climate change and reduce greenhouse gas emissions. In 1997, in Kyoto, Japan, 159 countries negotiated a treaty setting out legally binding reduction targets for six greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆) averaging 5.2 percent below 1990 levels for industrialized

countries over the commitment period 2008 to 2012 (Environment Canada, 2006).¹⁷ Canada signed the Kyoto Protocol in 1998 and after a Parliamentary debate, ratified it in December 2002 (Jaccard, 2005). Although Canada has signed the Kyoto Protocol, it would be extremely difficult for Canada to meet its objectives based on the projected “gap”— the difference between the projected greenhouse gas emissions level (based on the growth of energy use and production in Canada) and the Kyoto target (NRCan, 2006b; Jaccard, *et al.*).

The application of new technologies is considered as an important instrument for reducing greenhouse gas emissions and dealing with other sustainable development issues across all sectors. Greenhouse gas emissions in the upstream oil and gas industry have increased since 1989 according to the *Emissions Outlook* prepared for the National Climate Change Process, prepared by NRCan (NRCan, 1999). In the case of conventional oil pools, emissions have increased per unit of production due to declining pool pressure and the need for rising fuel consumption because of higher compression requirements. However, oil sands mining and upgrading are the most emission intensive, followed by bitumen, conventional heavy oil production, and conventional light oil production. New technology has been responsible for nearly 23 percent in greenhouse gas emission reductions per barrel of oil produced since 1990 (NRCan, 2003). Oil and gas production, particularly from oil sands, is expected to grow significantly and account for most of the growing gap between the Kyoto target and projected greenhouse gas emissions for Canada. The projected greenhouse gas emissions are

¹⁷ The Kyoto Protocol covers only those greenhouse gas emissions that are not already controlled by the 1987 Montreal Protocol on Substances that deplete the Ozone Layer, which covers chlorofluorocarbons, halons, carbon tetrachloride, and methyl chloroform. The GHG emissions covered under Kyoto are carbon dioxide, methane, nitrous oxide, HFCs, PFCs, and sulphur hexafluoride.

expected to be 828 mega tonnes (Mt) in 2010, implying a gap of 265 Mt above the Kyoto target or 32 percent above the projected level. Oil and gas production and upgrading are expected to account for 40 Mt or close to sixty percent of the 70 Mt increase in projected emissions from 2004 to 2010. It should also be noted that NRCan's oil and gas supply projections and hence emissions are lower than recent forecasts and announced oil sands expansions (e.g., the Canadian Association of Petroleum Producers, 2006b; NEB, 2006b).

Sustained high oil prices since have resulted in increased cash flows and profitability to oil sands operators. Further, given the outlook for high oil prices, the availability of a large resource base and the politically stable nature of Canada have been cited as factors for massive expansion in oil sands development. Table 3 A.1 provides recent major announcements on oil sands development. These new projects would account for significantly more oil sands supplies than projected by NRCan in 2006.

3.11 Performance and Cost Reductions

It is interesting to note how resource development and technological change are regarded in petroleum development. It is assumed that the best and cheapest reserves will be produced first. Therefore, as each barrel is produced and consumed, the remaining barrels become more and more expensive. Unless technology improves to make it easier to find and produce the next generation of resources, the average cost of production will inevitably rise over time (Bohi, 1999). Thus, the pressure to lower costs also highlights the need to undertake the development of new technologies. Both Canada and the United States are price takers. If oil

cannot be produced at less than the prevailing market prices, it can be imported into both countries from other producing nations. Governments have a strong interest in competitiveness because companies will relocate to lower-cost producing regions. The United States National Petroleum Council (1995) put this in context, noting that its view the competitive edge of the industry will increasingly depend on the ability to manage and apply technology effectively and rapidly. In addition, there is always a persistent concern about security of supply, particularly in the United States, which depends on foreign imports from politically unstable Middle Eastern countries and Venezuela.

The impact of technology on productivity can be examined by analysing the impact on the trend-based improvement in finding rates, success rates, costs, and the size of the resource base (Bohi, 1999). In Canada and the United States, success ratios have improved for both exploration and development wells. The improvement in success ratios is believed to be due to the application of advanced technologies, in particular 3D seismic, which are assisting companies to identify hydrocarbon deposits more easily. Although comprehensive data are not available to calculate the precise productivity implications of 3D seismic, anecdotal experiences of various companies (including Exxon, Amoco, Texaco, and Mobil) clearly demonstrate the impact on success rates with and without 3D seismic (Bohi, 1999).

3.12 Role of Government

Government plays a key role in innovation as discussed in Chapter 2, in terms of providing tax incentives and regulation, and in Chapter 3 regarding the Canadian context. This does

not need to be discussed again here but it is worthwhile noting that a key role of government in the sector is with regards to taxes, and regulations, including regulations to achieve safety and environmental goals, e.g., sustainable development and minimum environmental impacts. Government labs also work closely with industry. The role of government is briefly re-visited in discussing the investigative framework below. Porter (1998a) argues that one of the key reasons for environmental regulation is to create pressures that motivate companies to regulate and to raise the likelihood that product and process innovations in general will be environmentally friendly.

3.13 Application of Advanced Technologies

Technological innovation has long been a central characteristic of the energy system. Fri, (2003) notes that that the US National Academy of Engineering (2000) pronounced the electric system to be the most important engineering achievement of the 20th century – certainly no small honour. Technology today in the oil and gas industry is in sharp contrast to the days of the early explorers who identified oil and gas prospects on the basis of surface oil seeps, slicks along low places in creek valleys, or topographical formations. For most of history, however, the technology used in the upstream sector remained relatively unsophisticated. Bohi (1999) notes that until 20 years ago drilling was characterized by a group of roughnecks operating a rotary drilling rig and waiting for a gusher to erupt. Further, most oil and gas development until recently was confined to areas where it was easy to find and develop onshore resources and shallow-water offshore supply. However, over the past 15 to 20 years, there have been rapid developments and applications of technology in the

upstream petroleum industry. The motivation for improvement in productivity resulted from increasing pressure to reduce production costs. Significant motivation in the use of more advanced technologies in the upstream petroleum sector stemmed largely from competitive pressures to reduce costs in the face of lower oil and natural gas prices (Bohi 1999; Fri, 2003).

Development and application of technologies for the upstream oil and gas sector are complex. A broad range of technologies is being utilized for upstream oil and gas, such as reservoir evaluations, reservoir engineering, and drilling techniques. Technologies have a long life span in the natural resources sector. As well, it takes a long time to develop them (Schaan, 2003). This is true of the upstream oil and gas sector. Major technologies such as 3D/4D seismic, horizontal wells, and oil sands technologies took a long time to develop and required significant capital outlays. Their application also calls for significant investments. These technologies span the entire value chain of the industry – finding, developing, and producing oil and gas. They also cover a wide range of deposits including conventional, offshore, Arctic and heavy oil, and oil sands. Technologies include three-dimensional seismology (3D seismic), four dimensional seismology (4D), GPS surveying instruments, horizontal, directional and multi-bore drilling, offshore technology, computer technologies, and new improved materials (drill bits, drill pipes). Other new technologies are heavy oil upgrading processes, steam-assisted gravity drainage (SAGD), froths and emulsions leading to different extraction processes, improved pumping technology, and a host of others.

Upstream technologies cover a wide range of deposits including conventional, offshore, Arctic, and heavy oil deposits (oil sands and shale oil). 3D and 4D seismic and horizontal drilling are applicable to both onshore and offshore deep sea drilling. Technology and oil sands technology are complementary in nature and have been developed as a result of major breakthroughs in a number of areas including drilling materials, coiled tubing, pipes, motors, and computer technology to process significant amounts of data. 3D and 4D seismic and horizontal drilling are considered as important for oil and natural gas as the Bessemer process was perceived to be for producing steel and the Hall process for producing aluminium. These technologies may also be also considered Schumpeterian changes, given the number of other developments they are spawning. The breakthrough in SAGD has been crucial for the development of oil sands.

Advanced recovery technology, including enhanced oil recovery techniques, are required to recover a larger proportion of oil and gas in place. A relatively small portion of the oil in place is recovered from a producing reservoir; much of the oil is left in abandoned reservoirs. As a deposit is gradually exhausted, additional pressure must be added to produce the oil. The methods of enhanced recovery include water flooding, and CO₂ and steam injections. U.S. DOE notes that for every barrel of oil that flows from U.S. fields, nearly two barrels remain in the ground. Better technology is needed to find and produce much of this “left-behind” oil. Natural gas has a higher recovery factor. New technologies are also required to further reduce the costs of frontier, Arctic, and oil sands supplies.

Table 3A.2 provides a list of 6 technologies that have become important in the upstream petroleum industry. The application of these technologies on performance is investigated as part of the thesis.

Table 3 A.1

**Recent Announcements of New Oil Sands Projects or
Expansion Plans for Existing Projects**

Suncor Energy (Suncor) – Voageur growth strategy, a multi-phased plan designed to increase the company's oil sands production to a range of 500mb/d to 550 mb/d by 2010 to 2012.

EnCana Corporation (EnCana) will utilize SAGD technology to expand production from leases to 500 mb/d by 2010 to 2012.

Canadian Natural Resources Limited (CNRL) announced additional phases to its Horizon Oil Sands mining project to expand production to 500 mb/d by 2018 plus plans to expand its in-situ projects by 300 mb/d.

Imperial Oil Limited (Imperial) and Exxon Mobil filed a regulatory approval for three phase mining project of 300 mb/d at Kearl.

Shell Canada (Shell) announced expansion plans at both its Peace River and Jackpine Lake properties.

Petro-Canada partnered with UTS Energy Corporation and Teck Cominco Ltd. and received regulatory approval for the 100 mb/d Phase 1 of the Fort Hills mining project.

Husky Energy (Husky) received regulatory approval for its Sunrise project, with capacity of 200 mb/d over four phases, and disclosed plans to expand its Lloydminster upgrader to 150 mb/d of synthetic crude oil (SCO) and diluent capacity.

BA Energy Inc (BA) received approval for its three-phase 150 mb/d SCO production capacity Heartland Up-grader project, to be built in Stathcona County northeast of Edmonton, Alberta.

North West Upgrading Inc. (North West) has disclosed plans for its North West Upgrader, a three phase 200 mb/d merchant up-grader to be located in Sturgeon County, near Edmonton;

Total E&P Canada has acquired Deer Creek Energy and its Joslyn oil sands operations and leases.

Shell EP Americas, a subsidiary of Royal Dutch Shell PLC., recently purchased 10 properties in Northern Alberta targeting bitumen deposits situated in carbonate formations and formed a new company, SURE Northern Energy Ltd., to develop its new holdings.

Chevron Corporation (Chevron) recently acquired five heavy leases in Athabasca region and anticipates developing these leases using SAGD technology.

Source: National Energy Board, 2006b.

Table 3A.2

Six Major Upstream Oil and Natural Gas Technologies

Types of Technology	Description and Application
Three-dimensional seismology (3D seismic)	Uses sound waves to provide inference on the structure and properties of subsurface rock layers Yield higher quality images than two-dimensional 2D but more expensive and involves processing of a significant amount of data
Horizontal wells (directional wells)	Intersects the reservoirs at the side rather than from above, as compared to vertical wells Provides more contact with a pay zone (area containing oil and/ or gas) Much more expensive and riskier than a vertical well and needs highly trained professionals
Oil sands Technology	Several techniques exist to undertake surface and in-situ extraction, e.g., Steam Assisted Gravity Drainage System (SAGD) - recent innovation which uses two horizontal wells (one for steam and the other for producing)
Field recovery technology	Several enhanced oil recovery methods – water floods, CO ₂ injections, advanced pumping and production techniques to capture oil left behind.
Transportation and transshipment technology	Pipelines, valves, compression technologies
Sustainable development/ environmental technologies	CO ₂ emissions, natural gas flaring, and oil spillage reducing technologies and techniques to reduce the impact on the environment

CHAPTER 4

INVESTIGATIVE MODEL FRAMEWORK

This chapter discusses the investigative model framework, shown in Figure 4.1, to examine innovation in the upstream petroleum sector. The framework illustrates the drivers of innovation that impact adoption, the use of technology, and, in turn, performance. Panel 1 shows the drivers of innovation, Panel 2 the types of innovation activities and Panel 3 the performance indicators. The framework does not explicitly model collaboration and the role of government; these are examined in chapters 8 and 9 respectively.

Figure 4.1: Drivers of Innovation and Performance in Canada's Upstream Oil and Gas Sector

The framework draws on the discussion of the innovation literature and that of the upstream oil and gas industry, presented in earlier chapters.

4.1 Drivers of Innovation - Panel 1

Chapter 1 outlined the investigative questions of this research. Chapter 2 provided an in-depth discussion of innovation, and its drivers, and the impact on performance. Chapter 3 focussed on the upstream oil and natural gas sector, providing an overview and analysis of the sector and outlined the investigative questions of this research. The key factors considered for driving innovation in the sector include improving performance (e.g., lowering costs and increasing productivity), responding to global prices and competitive markets, and increasing productive capacity through adding new reserves. Other key factors in driving innovation are developing new resources, bringing on new projects, reducing impact on the environment, and developing oil and gas resources in a sustainable development manner.

As noted earlier in Chapter 3, low cost conventional reserves are declining. Lower cost resources are normally produced first (i.e., lower hanging fruits are picked first). In addition to the declining lower cost resources, non-conventional oil and natural resources are also more expensive to develop and are in more inaccessible and environmentally sensitive locations. The Canadian oil and gas industry operates in a competitive world environment. To continue to remain profitable, firms are interested in lowering costs through innovations.

Productivity in the economy is usually measured in terms of labour, as discussed in Chapter 3. In the upstream sector it is appropriate to look at productivity in terms of output per well, size of discoveries reserves added per footage drilled, success ratios, discovery rates, and finding costs (Bohi, 1999). These factors are related to costs and are important in driving firms to innovate.

The relevant market for Canadian producers is the United States (99 percent oil exports, 100 percent gas exports). The demand for energy supply from Canada in the U.S. is vast and will continue to grow (U.S./DOE/EIA, 2004; U.S./DOE/EIA, 2007b). Canada is viewed by the U.S. as a stable source of supply. And, as noted earlier, Canada is the largest oil exporter to the U.S. Increased market demand for Canadian energy from the United States places pressure to increase domestic oil and gas supply and move to producing higher cost resources. As well, oil demand growth in China and India can provide additional stimulus for developing Canadian resources. Firms operate in a volatile market environment; prices can rise and fall rapidly in the industry. As noted earlier, prices are determined in world markets and are significantly influenced by OPEC's output as well as geopolitical events. The difference between price and production costs impacts profitability. In recent years, prices have been strong, which is a reflection of geopolitical events. Natural gas prices, although determined in the North American markets can also be influenced by oil prices (set in the world market), as the two fuels can be substituted for each other in some cases, particularly for industrial usage.

Increasing productivity capacity involves bringing on additional reserves. For conventional oil and natural gas resources, this can involve bringing on stream new reserves found through exploration, adding more wells per square footage in an existing producing area, and enhancing recovery factors. Only a small percentage of oil is actually produced from a reservoir. Technology is required to recover a higher percentage of the oil in place. Expanding productive capacity also involves bringing on new projects (and expansions) in Canada's oil sands deposits, and northern gas and offshore resources. Finding oil and gas is becoming increasingly more difficult, thus advanced technologies are acquired to reduce costs.

Oil and gas production does involve a significant impact on the environment and, as discussed earlier there is significant interest in Canada in developing resources in a sustainable manner and in a way that reduces environmental impacts. This provides greater motivation to apply advanced technologies. The upstream oil and gas sector has made several commitments to develop Canada's resources in a sustainable manner and government policy also calls for the development of Canada's resources in a sustainable fashion.

Oil and gas developments are subject to significant regulations and oversight by the federal and provincial governments and regulatory agencies including Environment Canada, the Alberta Department of Environment, Natural Resources Canada, NEB, and the Alberta Energy Utilities Board (AEUB). The government of Canada has made several policy statements to reduce greenhouse gas emissions and improve air quality.

4.2 Modes of Innovation - Panel 2

The second panel in Figure 4.1 of the investigative model framework deals with innovation activities in the upstream sector. In discussing Panel 1 of the investigative model framework, it was noted that output factors – the pressure to lower costs, improve productivity, and increase productive capacity – could be considered important in driving innovation. As well, other factors including response to global markets, geology, the environment and sustainable development, collaboration and government could be key in impacting innovation. Two priorities of the recently released government S&T strategy (Industry Canada, 2007a) are the environment and environmental science technologies, and energy and the natural resources. One of the core principles of the strategy is collaboration among government, universities and industry.

An extensive discussion on innovation, R&D and the various types of innovation activities was provided in Chapter 2. According to a survey conducted by the NPC (1995), only a few companies carry out-in house R&D. There is greater reliance on service companies to provide technologies – most technologies in the firms in the upstream sector are adopted. A review of the literature, including the *Oslo Manual*, shows that sources of innovation go beyond R&D. According to the literature and the *Oslo Manual*, firms can obtain technology through acquiring machinery and equipment, advanced processes and external knowledge such as patents, inventions, licenses, know-how, trademarks, and software. In the oil and gas sector, firms acquire a large number of inputs including pipes, drill bits, compressors, valves, geological and geophysical services and processes that span the entire value chain of the

industry, seismic and drilling technologies field efficiency technologies (e.g., pumping and injections), oil sands, offshore, and field transportation. Firms could also take over other firms to acquire technology and have access to reserves. The six major technologies examined in this study are presented in Chapter 3 and their impacts are analysed later in subsequent chapters.

4.3 Performance and Innovation - Panel 3

Performance in the upstream oil and gas sector can be assessed along several parameters, capturing key cost measures, profitability, and environmental measures. Tornatzky and Klein (1992) note that it is important to use reliable measures as perceived by decision makers.

Several performance parameters used in this study are relevant across all three phases of operation: exploration, development and production. These parameters are examined with respect to specific technologies and each phase of operation.

These performance parameters are discussed below:

- Firms are faced with costs of exploring, developing, and producing oil and gas. These costs include land, geological and geophysical, and drilling expenditures. In the production process, firms are faced with operating costs. The exploration and development costs associated with one unit of oil or gas production are termed replacement costs. This is a complex measure in that reserves added could be revised upwards or downwards, and this will have an impact on replacement costs.

- In the production phase, operating costs are affected by the lifting costs – termed the “fixed” part of operating costs; the variable part involves the costs of separating out water from the oil. The operating costs are higher with greater water content. In oil sands operations, the issue is more the ratio of sand to oil. The higher the sand content in the ore, the higher the operating costs.
- Supply cost include exploration, development and production cost per unit of production – “full cycle.” Supply costs do not include any (externality) costs to society associated with environmental impacts.
- Productive capacity can be expressed in terms of the commercial resource base. When firms discover and develop new reserves they are increasing their productive capacity. Similarly, when they undertake the development of new projects they are adding to their productive capacity.
- Success ratio is the ratio of the number of successful discovery and development wells to the number of wells drilled. It is expected that firms would improve their success ratios of finding and developing oil and gas deposits with advanced seismic technologies.
- Targeting oil and gas reserves deposits is the extent to which firms can direct their drilling efforts to find, develop, and produce oil or gas.

- Management of supply involves the extent to which firms can bring forward supply to the market.
- Producer netbacks is the price received by the producer less the replacement and operating costs of a unit of production (one bbl oil /or an Mcf of natural gas).
- As noted earlier, production of oil and gas have significant impact on air emissions into the natural environment. This could involve reducing emissions and oil spills, and less destruction to the terrain. These impacts have been great cause for concern.
- Development of oil and gas is subject to a number of federal and provincial legislation, including the Canadian Environmental Protection Act, the Canadian Environmental Assessment Act, Navigable Waters Protection Act, the Fisheries Act, and the Indians Land Act.
- Greenhouse gas emissions are of great concern from the public policy perspective. Higher oil and gas production imply higher greenhouse gas emissions, particularly from oil sands production.
- People living near oil and gas production facilities, pipelines, refineries, and service stations are concerned about impacts on the environment and human health. Firms recognize the importance of good community relations. Efforts by companies to address environmental impacts could result in better community relationships.

- Currently, only about one third of the oil in place is recovered, but with improved recovery factors this can increase and thus effectively influence the size of the resource base. Enhanced recovery methods (to add to normal pressures of pumping oil and natural gas) could positively impact the amount of oil and natural gas that can be recovered and lower operating costs.
- Productivity can be expressed as the number of barrels of oil produced per well footage or per well or per worker.

It is expected that the application of these technologies would result in lowering exploration, development, and replacement and supply costs; improve productive capacity, productivity, the targeting of oil and reserve deposits, success ratios, the management of production, producer netbacks, and market shares; better meet environmental regulations / standards; reduce greenhouse gas emissions; and improve community relations. It is recognized that the relationship of these parameters are complex and that looking at these parameters at this level of detail is an effort to disentangle the impact of technology in the industry. Further, firms in the industry are frequently involved in more than one phase of operation which adds another layer of complexity and should be kept in mind when interpreting these parameters. Tornatzky and Klein (1982) note that studies can sometimes yield the opposite relationship than is expected the basis of theory.

CHAPTER 5

RESEARCH METHODOLOGY

This chapter discusses the sample used for this study, the process involved in surveying companies, the support and endorsement received from key industry organizations in undertaking this study, the coverage of the survey questionnaire, and the approaches to be used for the data analysis of this research.

5.1 Research Sample

The study is based on a survey of firms in the upstream petroleum sector, specifically exploration, development, and production of crude oil and natural gas companies in Canada. The majority of the companies are both oil and natural gas producers. Additionally, some of them are involved in non-conventional extraction (e.g., oil sands). The sample was drawn from *The Canadian Oil Register* (Nickle's, 2005). These firms fall under Code 211 of the North American Industry Classification System (NAICS). The *Canadian Oil Register* provides the names of the various companies in the oil and gas industry, types of operations in which companies are involved, their addresses and the names of their respective chief executive officers and other key officials. Although hundreds of companies operate in the sector, many are relatively small. Moreover, many companies are involved only in providing services to the operators (service companies are involved in providing a range of services such as drilling rigs, drilling activity, supplies, surveying, well servicing, mapping and engineering, and recovering petroleum gases). The *survey frame* for this study consists of an estimated 210 oil exploration, development, and production companies listed in the

Canadian Oil Register 2003-2004. These companies were chosen once they showed that they were exploration, development, or production companies. Most of these companies are located in Western Canada, particularly Alberta, with a majority of the head offices in Calgary. The upstream sector is relatively concentrated with 25-30 firms accounting for most of the industry's activity. Many small companies have operating interests in other firms and receive royalties, some are extremely small 2 persons (family run), some firms were also in mid-stream operations and others were listed in the Oil Register although they are not operators in Canada but have operating interests overseas. According to the Nickle's *Oil Bulletin* (April 19, 2004), EnCana dominated drilling activity in Canada and accounted for 25 percent of the 6,278 wells drilled by all operators in the first quarter of 2004. In addition to the *Canadian Oil Register*, other industry publications including Ross Smith Energy (Energy Update Report¹⁸) are also helpful in identifying companies and their respective sizes and operations.

5.2 Target Rate of Responses

Innovation surveys are relatively new and the technique is still evolving. Undertaking a survey is a major and complex exercise and response rates can be low due to time constraints on companies requested to respond to the survey. Also finding those companies who have the wide scope of knowledge required to correctly answer a survey questionnaire is challenging. Furthermore, companies in the industry are fiercely competitive and are concerned about divulging information. Several approaches were used to have the

¹⁸ Ross Smith Energy Group Ltd. 2004. The company now publishes the *Energy Update Report* which was previously published by ARC Financial.

questionnaire completed. Mail, faxes, e-mail, and the telephone were used to receive responses to the questionnaire. In some instances, a number of phone calls were necessary to solicit co-operation from companies. In most cases, senior vice-presidents of companies or presidents were contacted directly. Leads from government and industry contacts, and from conference participants were followed to obtain the target rate of the survey.

In the best of circumstances, surveying companies is a challenging task. Companies receive many surveys and are reluctant to fill them out because this could be time consuming for their operations. As well, companies operate in a competitive environment and are usually hesitant to part with internal company information. Even in some cases where firms would like to fill out the questionnaires, the nature of their operations prevents them from adequately answering the questions. Oil and natural gas firms are fiercely competitive and they are very concerned about divulging information. The type of information sought for this study is in-depth and covers key aspects of company operations. A few companies required assurances that their responses would be held confidential and only be used for academic purposes. The expectation was to receive responses from about 50 firms that account for approximately 30 percent of the industry's production and revenues. Several experts and industry associations suggested that an optimistic scenario could yield about 30 respondents and that this may be sufficient to get a good perspective on innovation in the sector.

With several repeated calls to senior company officials, and assistance and endorsement from industry associations – in particular the Canadian Association of Petroleum Producers, the Energy Council of Canada, and the Heavy Oil Association of Canada – the number of

companies proposed for the research was surpassed. In total, 68 responses were received, accounting for most of the industry's revenues and production. The responses are discussed more fully in Chapter 6. As well, during the course of this study, experts at NRCan, Alberta Government, the NEB, and member companies of CADOC, CEPA, and PTAC were contacted directly to obtain information and anecdotal perspectives on innovation in the upstream sector. The Canadian Association of Petroleum Producers' membership of 140 companies accounts for 95 percent of Canada's oil and gas production.

By way of background, six companies indicated that they could not fill out the questionnaire because they were not in the upstream sector *per se*; they were mid-stream and service suppliers. Three companies indicated that they could not fill out the questionnaire for confidentiality reasons. Six companies were out of business and six had merged. Four of the companies that had merged were captured in the survey. Several companies indicated that because they were too small and not directly involved in innovation *per se* they could not fill out the questionnaire. The small companies are sometimes not directly involved in the day-to-day operations of the industry but have various types of farm-in arrangements with other companies who are the main operators of oil and natural gas projects.¹⁹

¹⁹ Farm-in arrangements involve participation in a project or lease development as a silent partner (e.g., a partner may contribute finance, property, land concessions, and /or lease to share in revenues). These types of arrangements are not limited to small companies but are industry-wide practices.

5.3 Industry Association Support

Great endorsement and support for this research were received from the Canadian Association of Petroleum Producers. As noted above the Canadian Association of Petroleum Producers' membership account for most of industry's production. In fact, the Canadian Association of Petroleum Producers expressed great interest in the study. The Canadian Association of Petroleum Producers circulated the questionnaire to member companies that belong to its Innovation Committee. The Chairman, Dr. Murray Stewart of the Energy Council of Canada, sent the questionnaire package to member organizations with a covering letter that he prepared. His letter was sent to higher-level colleagues in the industry including presidents of other industry associations. Also, the president of the Heavy Oil Association of Canada sent the survey package to members of his association as well.

A number of experts from other parts of the petroleum industry were contacted to discuss innovation in the upstream sector:

- The Canadian Gas Association (CGA);
- The Canadian Association of Oil well Drilling Contractors (CAODC); and
- The Canadian Energy Pipelines Association (CEPA).

CGA and CEPA include downstream companies and CAODC drilling service companies.

5.4 Survey Instrument

A copy of the survey questionnaire (see Appendix 4) was developed and distributed to oil and gas firms in the Canadian upstream sector. The questionnaire was pre-tested with

knowledgeable individuals in the energy field who had in-depth knowledge in the Canadian upstream oil and gas sector. They reviewed the survey questionnaire and provided detailed comments. The author had the opportunity to discuss their comments in face-to-face meetings and by phone.

Questionnaire Design

Companies within the sampling frame were provided a package containing:

- 1) a letter of introduction/cover letter;
- 2) the questionnaire; and
- 3) a form by which the respondent could indicate whether he/she would like a copy of the results.

The covering letter was written on Eric Sprott School of Business official letterhead to provide the legitimacy of the study as academic research. The cover letter was also co-signed by the Director of the School at that time.²⁰ The letter served to introduce the author, describe the importance and scope of the research, and request the recipient's participation in the study. Assurance was given that all responses could be treated with confidentiality and would be aggregated, and that the study was intended for academic purposes only. The letter offered the respondents the opportunity to contact the thesis supervisors if they so wished.

The questionnaire consisted of mainly of a rating scale, and yes/no questions. Several questions were quite detailed consisting of several parts in order to obtain an in-depth

²⁰ The School is now a Faculty and a Dean has recently been installed.

understanding of the sector. The questionnaire sought information on a wide range of issues on innovation in the sector including:

- the size of their operations in terms of the number of employees and revenues;
- years of operation of their company;
- the types of operations in which firms were involved (nature of business) e.g., crude oil and natural gas exploration, development, and production companies; oil sands production (mining, upgrading and in-situ); coal bed methane gas development; and exploration and refining companies;
- the drivers of innovation – firms were asked about their views on a pre-set list including cost reductions, productivity, recovery factors, productive capacity including accessing new reserves and bringing on new projects, improving exploratory success, external conditions such as world crude oil prices, supply demand conditions, environmental regulations, reducing greenhouse gas emissions to meet Kyoto targets, government incentives, and community relations;
- the types of innovation activities – including R&D, acquisition of advanced equipment, processes, and software and acquisition of other external knowledge such as R&D, patents, inventions, licenses, know-how, and packaged software;

- the use of major technologies in exploration, development, and production activities. The technologies listed include 3D seismic (and 4D seismic), Horizontal (directional wells and multi-bore wells), field recovery technology, advanced oil sands recovery (e.g., steam assisted gravity drainage SAGD), transportation and transshipment technology and sustainable development /environmental technology (e.g., CO₂ and natural gas flaring reducing technologies and oil spillage reducing);
- the impact of select technologies on performance in exploration, development, and production activities using performance variables such as costs, productivity, capacity expansions, net-backs to producers, greenhouse gas reductions, community relations, better environmental standards, and regulation;²¹
- the involvement in collaborative agreements and whether they were with universities and colleges, federal government, research institutes, provincial and territorial governments, competitors, suppliers of equipment, and foreign companies;
- the reasons for cooperative agreements including sharing costs, sharing risks, sharing facilities, accessing new knowledge, accessing R&D developing new markets; and
- the level of importance of government support such as R&D credits (e.g., SR&ED), government technology and support programs, government fiscal framework with

²¹ The price of a barrel of oil less production costs before taxes is the net-back to the producer.

respect to exploration and development, partnerships with government labs, and government support for training.

5.5 Data Analysis

The survey responses are analysed using descriptive statistics, factor analysis, and regression analysis. The data analyses are presented in chapters 6 to 9. The statistical software package SPSS for Windows was used to analyse the data.²² These chapters present descriptive data on the sample of the nine questions of the questionnaire. The size distribution of companies who responded to the survey and their years of operation are presented. Their reliance on the various forms of technology, their reliance on major technologies, the drivers of innovation, the impact of technology, collaboration and the role of government are covered in these chapters. This information is presented using graphs, tables, cross tabulations, regression coefficients, and various types of descriptive data. Chapter 10 will provide a discussion on the results of chapters 6 to 9.

²² SPSS provides useful statistics to test for outliers, normal distribution multicollinearity (independent variables highly correlated with each other).

CHAPTER 6

DESCRIPTIVE DATA ANALYSES

This chapter provides an overview of the sample, the size of companies, the factors driving innovation, and the reliance on the various modes of innovation and major technologies in each phase of the industry – exploration, development and production.

6.1 Overview of the Sample

The survey results could be considered highly representative of the industry in terms of exploration, development and production activities. Overall, 68 responses were obtained from industry participants to the survey.²³ The sample represents about 40 percent of the estimated number of operators in the industry.²⁴ When adjustments are made for companies who indicated that they were too small and are not directly involved in the day-to-day operations of the industry the response rate goes up to over 50 percent. Further, this sample covers the companies that account for most of the revenues, employment, production, and reserves in the upstream oil and gas industry. In addition, most of the oil sands producers were captured in the survey. Oil sands production is accounting for an increasingly large share of Canada's oil production. An understanding of how innovation takes place in this area is critical to developing a long term view of Canada's oil and gas supply.

²³ Several small firms' decisions on innovation are also reflected through large companies with which they have operating agreements. This survey captures almost all firms in the top end of the industry.

²⁴ The number of companies estimated from the Oil and Gas Registry are about 200. When adjustments are made for "one man" operations, the number drops to 170. When further adjustments are made for those who indicated that they could not answer the questionnaire because of their size, use of technologies, etc. the number falls to 130.

The survey responses could be considered as official company information in that in most cases it came from the president or vice presidents. In some cases, the responses to the survey were routed through the communications department of companies for official company approval. The sample captures most companies in the industry with more than 1,000 employees and annual revenues above \$1B. As noted earlier, a number of companies could not adequately respond to the survey. Taking account of these companies, only a handful of companies that could impact the survey results are not captured in this survey. Further, several of these companies have joint ventures with those who responded to the survey and are thus in a way indirectly captured in the study.

6.1.1 Size of Companies

Firms were asked to provide the number of employees and their revenues to help in understanding the size of their operations. Statistics Canada, which was directly consulted, does not have a definition of firm size *per se*. One measure that has been used by Statistics Canada to compare firms across industries is company revenue using categories of less than \$1M, \$1-5, \$5-25M and more than \$25M. Table 6.1 provides the distribution of companies in terms of revenues. Most firms who responded to the questionnaire of this study have revenues well in excess of Statistics Canada's large firm classification, as can be seen from Table 6.1. In fact, there are several companies with over a billion dollars in revenues.

Table 6.1
Size of Companies in Terms of Revenues (Millions of Dollars)

Size distribution of companies Revenues (\$M)		Frequency (*)	Percentage of Respondents (%)	Cumulative Percentage (%)
Small	Less than 49	23	34.3	34.3
Medium	50 - 199	14	20.9	55.2
Large & Integrated	More than 200	30	44.8	100.0
Total		67.0	100.0	100.0

(*) One company did not provide the revenue information.

More detailed information on revenues of firms is provided in Table 6.A1 at the end of chapter 6.

Statistics Canada recognizes that firm size could be industry specific and it is left to the researcher to determine size. Industry Canada made a similar point and noted that it uses employees to measure size. The Export Development Corporation defines small firms as those firms with export sales of under \$1M (Industry Canada, 2007b). It should be noted that measures used for the goods producing, service, and goods exporting firms may not be appropriate for the oil and gas sector given its capital intensive nature. The terminology used with respect to size in the industry is small, medium, and large and integrated firms. Researchers and financial companies have used revenues, market capitalization, employees, and barrels of oil equivalent (oil and gas combined) in terms of reserves. It is worthwhile noting that, given the cyclical nature of the industry, these parameters can quickly fluctuate. A preferable definition of analysis used by Statistics Canada is one based on the number of employees. It was noted, however, that it is difficult to obtain this type of data. This survey also collected information on the size of the companies with respect to the number of

employees as well. Table 6.2 provides a breakout into three groups: small, medium, and large and integrated, based on the companies who responded to the survey.

Table 6.2

Size of Companies in Terms of Employees

Size Classification	Size Distribution	Number of Firms	Percentage (%)	Cumulative Percentage (%)
Small	Less than 20	26	38.2	38.2
Medium	20-100	17	25.0	63.2
Large & Integrated	More than 100	25	36.8	100.0
Total		68	100.0	100.0

Greater details on firm size distribution with respect to employees are provided in Table 6.A2 at the end of this chapter.

6.1.2 Years of Operation

Table 6.3 shows the years that these firms have been in operation. About 30 percent of the companies have been in operation for 4 years and approximately 70 percent have been in operation more than 5 years. More than 45 percent of firms have been in operation for more than 10 years.

Table 6.3

Years of Operation of Firms

Years of Operation	Frequency	Percent
Less than 5 years	20	29.4
5 – 10 years	17	25.0
More than 10 years	31	45.6

It should be recognized that the upstream oil and gas sector is a dynamic industry and that merger activity has been important in the industry during the past 10 years; this should be kept in mind when examining the relationship of size and the years of operation. A comparison of the years of operation and the size of firm are provided in Table 6.4

Table 6.4

Comparison of Years of Operation and Firm Size

	Small Less than 20 Employees	Medium 20-100 Employees	Large & Integrated More than 100 Employees	Total Number of Firms
Less than 5 years	11	7	2	20
5 – 10 years	4	8	5	17
More than 10 years	11	2	18	31
Total Number of Firms	26	17	25	68

The data show:

- that small firms fell mainly in the less than 5 years and more than 10 years categories;
- medium size firms fell in mainly in the less than 5 years and the 5-10 years categories;
- large firms fell mainly in the over 10 years category;
- small firms account more than 50 percent of firms in the less than 5 years old category and 35 percent of the more than ten years old firms group;
- medium size firms account for 33 percent of firms in the less than five years and 47 percent of firms in the 5-10 years group; and
- large and integrated firms account for 58 percent of firms in the over ten-year category.

6.1.3 Types of Industry Activity

Companies were asked to provide the types of operations in which they were involved.

Of the 68 companies who responded to the survey, their involvement is as follows:

- 57 companies were involved in exploration;
- 67 companies were involved exploration and development; and
- 67 companies were involved in development and production.

Firms were asked about their involvement in oil sands operations. The results show that:

- a total of 17 firms were involved in oil sands operations and
- 9 were involved in mining, 7 in upgrading and 12 had in-situ operations.

Firms were asked about their involvement in coal-bed methane (CBM). The results show that 29 firms or 43 percent of the total respondents were involved in CBM. One of the reviewers of the questionnaire had suggested that it would be worthwhile to get a sense of the number of companies involved in CBM operations as this was becoming an area of great interest. CBM currently accounts for an insignificant amount of gas supply in Canada but it is believed that the source of supply could have a big impact on long-term supply as Canadian conventional supplies decline. Unconventional gas reservoirs such as coal bed (natural gas trapped in coal seams), tight sands, and fractured shales are becoming increasingly important as the domestic conventional gas supply declines.²⁵

²⁵ There is a significant coal-bed resource base in Canada and the US. It is estimated that Alberta has about 500 TCF of CBM suitable for exploration (Alberta Geological Survey –

In discussion with industry experts, it was revealed that the U.S. experienced problems with water disposal in the development of CBM. This resulted in claims by farmers that the water was contaminating their aquifers. CBM is very costly to produce and the environmental impacts are still not well understood. A key point made by operators and experts, however, was that water contamination while important, is not as big a concern in Canada as in the U.S. since the large deposits of coal seam gas in Canada can be found mostly in dry areas. One comment received was that total drilling activity is expected to fall mainly due to lower CBM exploration and development. 3D/4D seismic would be useful to develop CBM but major breakthroughs in technology according to industry would be required to lower costs and address potential environmental issues.

6.2 Factors Driving Innovation

Companies were asked to rate the importance of 20 factors in driving innovation in their companies on a scale of 1 to 5 where 1 = not at all important, 2 = somewhat important, 3 = important, 4 = very important, and 5 = extremely important. These factors fall into four main categories: output (mainly cost related); market environment (prices and supply / demand conditions); geological (factors such as success ratios, targeting oil and gas, exploratory costs); and environment (greenhouse gas emission reductions, environmental regulations etc.).

http://www.ags.gov.ab.ca/activities/CBM/coal_and_cbm_intro.shtml). For the US, CBM production was 1.56 Tcf in 2001 - this represents more than a 17-fold increase over a decade.

Table 6.5 shows the 20 drivers of innovation and their relative importance of each driver of innovation activity in terms of the mean values of the responses from companies. The drivers with the highest mean values are: increasing productive capacity, increasing productivity, reducing development costs, meeting environmental regulations, and improving success ratios.

Table 6.5
Factors Driving Innovation in the Upstream Oil and Gas Sector

	Mean	Std. Deviation
Responding to world crude prices fluctuations	2.22	1.183
Responding to supply demand conditions	2.41	1.109
Responding to natural gas prices fluctuations	2.46	1.165
Proximity to reflect synergy	2.53	1.178
Improving market shares	2.63	1.455
Reducing greenhouse gas emissions	2.63	1.233
Reducing Unit Supply Cost	2.85	1.438
Improving community relations	3.34	1.128
Reducing transportation and transshipment	3.38	1.270
Reducing environmental impacts	3.49	1.126
Reducing Unit Exploration costs	3.53	1.419
Improving targeting oil and gas reserves	3.72	1.256
Increasing recovery factors	3.85	1.188
Improving success ratios	4.03	1.119
Meeting environmental regulations	4.13	1.145
Reducing Unit Operating costs	4.16	1.045
Reducing Unit replacement costs	4.19	1.083
Increasing productivity	4.22	.990
Reducing Unit development costs	4.26	1.101
Increasing productive capacity	4.28	1.077
Valid N (listwise) = 68		

The next most important are factors such as reducing environmental impacts, reducing transportation and transshipment costs, and improving community relations. At the lower end are world oil prices, natural gas prices, supply demand conditions, and reducing greenhouse gas emissions.

Chapter 7 presents principal component analysis, correlation and regression analyses of these drivers.

6.3 Modes of Innovation

Firms were asked about their reliance on modes of innovation. They were asked to rate the following modes of innovation activities: internal R&D, acquisition of advanced modern equipment, acquisition of advanced processes, and acquisition of other external knowledge. The scale used was 1 to 5 where: 1 = not at all important, 2 = somewhat important, 3 = important, 4 = very important, and 5 = extremely important.

The responses show that companies relied on all modes of innovation but to a lesser extent on R&D. The data show that:

- 87 percent of firms found acquisition of advanced machinery and equipment to be important to extremely important;
- 76 percent saw the acquisition of advanced processes as being important to extremely important;

- 81 percent noted that acquisition of other processes to be important to extremely important; and
- 44 percent of firms found R&D to be important to extremely important. A high percentage (30 percent) saw R&D to be not at all important.

Table 6.6 shows the mean value of the responses with respect to each mode of innovation activity. The results indicate that the mean value of R&D falls below 3.0 while the mean value of external sources of technology ranges between important to very important. This supports the view that firms rely more on external knowledge than on internal R&D.

Table 6.6

Mean Values of the Various Modes of Innovation

	Mean	Std. Deviation
Innovation activities - Internal research and development (R&D)	2.49	1.310
Innovation activities - Acquisition of advanced modern equipment	3.50	.970
Innovation activities - Acquisition of advanced processes	3.34	1.141
Innovation activities - Acquisition of other external knowledge	3.29	1.080

In comparing the means of various groupings of firms, it was found that, small companies ranked the lowest in terms of R&D. Medium sized companies were just slightly higher than large and integrated companies in this respect. Acquisition of advanced machinery and equipment was in the same order of magnitude for the three groups. Large companies had the highest reliance on advanced processes followed by medium sized firms and then small

firms. It is interesting to note that the levels of reliance on other external knowledge by small and large and integrated firms were about the same but for the reliance by medium sized firms was a bit lower.

In looking at the relation of innovation activities, it was found that acquisition of advanced machinery and equipment is highly correlated with acquisition of advanced processes having a Pearson correlation coefficient of .816 (.01 level), and with acquisition of other advanced external knowledge .556 (.05 level). The Pearson correlation coefficient of acquisition of other external knowledge and advanced processes is .463 and significant at the .05 level. R&D is moderately correlated with other innovation activities. There is little correlation between R&D and acquisition of advanced modern equipment, acquisition of advanced processes, and other external knowledge as can be seen from Table 6.7.

Table 6.7

Correlation Coefficients of Innovation Activities

	Internal research and development (R&D)	Acquisition of advanced modern equipment	Acquisition of advanced processes	Acquisition of other external knowledge
Internal research and development (R&D)	1	.253(*)	.258(*)	.182
Acquisition of advanced modern equipment	.253(*)	1	.816(**)	.556(**)
Acquisition of advanced processes	.258(*)	.816(**)	1	.463(**)
Acquisition of other external knowledge	.182	.556(**)	.463(**)	1

(*) Correlation is significant at the 0.05 level (2-tailed).

(**) Correlation is significant at the 0.01 level (2-tailed).

In all areas of operation – exploration, development and production – reliance on acquisition of advanced machinery and equipment exceeded the reliance on R&D as shown in Table 6.8. As well, the means for the acquisition of advanced processes and other external knowledge (e.g., patents, inventions, licenses, know-how, and packaged software) exceeded that of internal R&D.

Table 6.8

**Reliance on Innovation Activities:
Comparison of the Means of Company Ratings**

	Internal research and development (R&D)	Acquisition of advanced modern equipment	Acquisition of advanced processes	Acquisition of other external knowledge
Exploration	2.58	3.54	3.42	3.33
Development	2.45	3.50	3.36	3.33
Production	2.46	3.46	3.32	3.29

It is also worthwhile noting that there is little difference in the mean values of innovation activities across activities.

6.4 Reliance on Specific Technology in Specific Industry Activity

Companies were asked to rate the extent that they used the following major technologies in their operations in exploration, development, and production. The scale used was 1 to 5 where: 1 = not used; 2 = used very little; 3 = used moderately; 4 = used quite frequently; and 5 = used extensively.

6.4.1 Technology Use and Exploration Activity

In exploration, companies were asked to rate the use of the following three areas of technologies:

- 3D and 4D and other advanced seismic technologies;
- Horizontal (directional) wells – multi-bore;
- Sustainable development / environmental technologies (e.g., for reducing CO₂ emissions, natural gas flaring, oil spillage etc.).

It was found that firms use of 3D/4D and other advanced seismic technologies ranked the highest, followed by horizontal wells and then sustainable development technologies. Almost 75 percent of firms indicated that they use 3D/4D and other advanced seismic technologies quite frequently and extensively as compared to 47 percent for horizontal wells and 40 percent for sustainable development technologies. The mean values of the use of the three technologies were also estimated and are shown in Table 6.9. The results show that 3D/4D seismic technology has the highest mean value. The *Paired-Samples T Test* was used to test for significance of the difference of the means. It was found that the mean value of 3D/4D seismic is statistically different than that of horizontal wells and sustainable development technologies. When the use of horizontal wells is compared to sustainable development, the difference is not found to be statistically significant. The results suggest on average that 3D/4D seismic is the most used technology in exploration.

Table 6.9

Extent of Use of Major Technologies in Exploration Activity ⁽¹⁾

Technologies	Mean	Std. Deviation
Use of 3D seismic in exploration activities	3.95 (***)	1.315
Use of horizontal (directional) multi-bore wells in exploration activities	3.32	1.256
Use of sustainable development and environmental technologies in exploration activities	3.18	1.136

(1) – 57 companies were involved in exploration activity.

(***) – The mean differences of horizontal wells and sustainable development technologies are significant at the .001 and .002 levels respectively.

6.4.2 Technology Use and Development Activity

Companies involved in development activity were asked to rate the use of the following three areas of technologies:

- 3D/4D and other advanced seismic technologies;
- Horizontal (directional) wells – multi-bore; and
- Sustainable development / environmental technologies (e.g., for reducing CO₂ emissions, natural gas flaring, oil spillage etc.).

The results show that the use of 3D/4D ranked the highest in terms of use, followed by horizontal wells and then sustainable development technologies. About 73 percent of firms noted that they used 3D/4D and other advanced seismic technologies quite frequently to extensively as compared to 53 percent for horizontal wells and 46 percent for sustainable development technologies. Table 6.10 shows the extent of use of the major technologies in development activity.

Table 6.10

Extent of Use Major Technologies in Development Activity ⁽¹⁾

Technologies	Mean	Std. Deviation
Use of 3D/4D and other advanced seismic technologies in development activities	3.90 (*)	1.269
Use of horizontal directional multi-bore wells in development activities	3.56 (*)	1.236
Use of Sustainable development & environmental technologies in development activities	3.15	1.080

(1) – 59 companies were involved in development activity.

(*) – The mean differences of 3D/4D and horizontal wells and sustainable development technologies are significant at the .05 and .005 levels respectively.

Overall, there is a significant use in advanced upstream technologies with 3D/4D seismic as being the highest in terms of their mean value. Again, using the *Paired-Samples T Test*, it was found that the difference in means of 3D/4D seismic with horizontal wells was significant at the .05 level and with sustainable development technologies at the .005 level. The relatively high reliance of 3D/4D seismic and horizontal wells in the development phase may suggest some level of complementarity. The use of horizontal wells in this phase of activity is higher than in exploration. But when the means are compared, 3D/4D seismic in development activity is just slightly below that of exploration activity. The use of sustainable development technologies is about the same for both exploration and development activities.

6.4.3 Technology Use in Production Activity

Companies involved in production activity were asked to rate the use of the following six areas of technologies:

- 3D and or 4D and other advanced seismic technologies;
- Horizontal (directional) wells – multi-bore;
- Field recovery technology (e.g., enhanced oil recovery methods water floods, CO₂ injections, advanced pumping and production techniques);
- Advanced oil sands recovery processes (e.g., SAGD);
- Transportation and transshipment technology; and
- Sustainable development / environmental technologies (e.g., for reducing CO₂ emissions, natural gas flaring, oil spillage etc.,).

For the production sector, greatest importance is placed on advanced recovery technology. The results show that 48 percent of firms noted that they used advanced field recovery methods quite frequently to extensively – the highest level among the six technologies. Table 6.11 shows the extent of use of these technologies. The mean value of use of advanced field recovery technologies ranked the highest for production activities followed closely by horizontal wells and sustainable development technologies. Firms are interested in improving recovery factors and capturing more of the “oil left behind.”

Table 6.11

Extent of Use of Major Technologies in Production Activity ⁽¹⁾

Technologies	Mean	Std. Deviation
Use of advanced field recovery technology in production activities in production activities	3.25 (***)	1.164
Use of Horizontal wells in production activities	3.19	1.293
Use of sustainable development and environmental technologies in production activities	3.02	1.171
Use of 3D-4D seismic in production activities	2.79	1.557
Use of transportation and transshipment technologies in production activities	2.08	.989
Use of oil sands recovery processes in production activities (e.g., SAGD) ⁽²⁾	1.89	1.557

(1) 63 companies were involved in production activity.

(2) When 17 oil sands operators alone (who responded to the survey) are considered – the mean goes up to 3.1961 with a standard deviation of 1.30202.

(***) The mean difference with oil sands technology and transshipment technology is highly significant at the .0001 level and for 3D/4D technology at .0001 and with seismic technology at .05. There is no significant difference with horizontal wells and sustainable development.

The *Paired-Samples T Test* was used to test for significance of the difference of the means.

It was found that the mean differences of advanced field recovery technology, horizontal wells, and sustainable development technologies were not statistically significant. However, the mean differences for advanced field recovery technology, 3D/4D seismic, and oil sands technology and transportation and transshipment technologies were found to be statistically significant at the .05, .0001, and .0001 level respectively. This suggests the importance of advanced field recovery technology, horizontal wells and sustainable development technologies in the production phase of the industry.

Across the upstream sector, the results show that 3D/4D, and advanced seismic technologies, horizontal wells, and advanced recovery technology are the most used in the upstream oil and gas industry. Further, 3D/4D and advanced seismic technologies are used most in the exploration phase, 3D/4D in the development phase, and advanced recovery technology in the production phase. It is worthwhile noting that when only oil sands operators are considered, the mean value for the use of oil sands technology increases to 3.19. Making this adjustment is reasonable in that firms who are not involved in oil sands operations do not have use for this technology. In spite of this adjustment, the use of advanced field recovery technology still remains the highest.

6.5 Conclusion

This chapter provided a discussion on the sample and descriptive analyses of the data. Overall, the sample is considered representative of the industry and there were strong interests and support for the study. Several of the drivers were seen as very important for innovation in the industry. The drivers with the highest mean values are: increasing productive capacity, increasing productivity, reducing development costs, meeting environmental regulations, and improving success ratios.

The data showed a strong reliance on external sources of technologies as reflected by the high level of acquisition of advanced machinery and equipment, advanced processes, and acquisition of other external knowledge. On the other hand, the data showed that there is relatively little reliance on internal R&D. This is true at the overall industry level and for the

three phases of activity – exploration, production and development. The data also show that firms' use of the major technologies under study was ranked very high by the industry. 3D/4D seismic technologies ranked the highest in exploration activities and development activities. The use of advanced field recovery technology ranked the highest for development activities. When only oil sands operators are considered, the mean value for the use of oil sands technology goes up to 3.19, or higher than any other technology in the production phase.

The following chapter will examine the key drivers on innovation activity through regression analyses and the impact of the major technologies on performance through descriptive analyses.

Table 6A.1

Size Distribution of Companies: Revenues (Millions of Dollars)

Size distribution of company Revenues (\$M)		Frequency	Percent Of Sample	Valid Percent	Cumulative Percent
Valid	Less than 49	23	33.8	34.3	34.3
	50 – 199	14	20.6	20.9	55.2
	200 – 499	11	16.2	16.4	71.6
	500 – 999	3	4.4	4.5	76.1
	Over \$1000	16	23.5	23.9	100.0
	Total	67	98.5	100.0	
Missing	999	1	1.5		
Total		68	100.0		

Table 6A.2

Size Distribution of Companies: Employees

Number of Employees		Frequency	Percent Of Sample	Valid Percent	Cumulative Percent
Valid	Less than 20	26	38.2	38.2	38.2
	20 – 49	7	10.3	10.3	48.5
	50 – 99	10	14.7	14.7	63.2
	100 – 249	7	10.3	10.3	73.5
	250– 499	3	4.4	4.4	77.9
	500 – 999	1	1.5	1.5	79.4
	Over 1000	14	20.6	20.6	100.0
	Total	68	100.0	100.0	

Figure 6 A.1: Drivers of Innovation – Reducing Unit Exploration Costs

Figure 6 A.2: Drivers of Innovation – Reducing Unit Development Costs

Figure 6 A.3: Drivers of Innovation – Reducing Unit Replacement Costs

Figure 6A.4: Drivers of Innovation – Reducing Unit Operating Costs

Figure 6 A.5: Drivers of Innovation – Reducing Unit Wellhead Supply Costs

Figure 6 A.6: Drivers of Innovation – Responding to World Crude Price Fluctuations

Figure 6 A.7: Drivers of Innovation – Responding to Natural Gas Price Fluctuations

Figure 6 A.8: Drivers of Innovation – Responding to Supply Demand Conditions

Figure 6 A.9: Drivers of Innovation – Increasing Productive Capacity

Figure 6A.10: Drivers of Innovation – Increasing Productivity

Figure 6 A.11: Drivers of Innovation – Increasing Recovery Factors

Figure 6 A.12: Drivers of Innovation – Improving Success Ratios

Figure 6 A.13: Drivers of Innovation – Improving Targeting Oil and Gas Reserves

Figure 6 A.14: Drivers of Innovation – Reducing Transportation and Transshipment Costs

Figure 6 A.15: Drivers of Innovation – Proximity to Other Companies in the Same Business

Figure 6 A.16: Drivers of Innovation – Reducing Greenhouse Gas Emissions

Figure 6 A.17: Drivers of Innovation – Reducing Environmental Impacts

Figure 6 A.18: Drivers of Innovation – Meeting Environmental Regulations

Figure 6 A.19: Drivers of Innovation – Improving Market Shares

Figure 6 A.20: Drivers of Innovation – Improving Community Relations

Table 6A.3

Use of 3D/4D seismic in exploration activities

Level of Importance	Frequency	Percent Of Sample	Valid Percent	Cumulative Percent
1	5	8.8	8.8	8.8
2	5	8.8	8.8	17.5
3	5	8.8	8.8	26.3
4	15	26.3	26.3	52.6
5	27	47.4	47.4	100.0
Total	57	100.0	100.0	

Table 6A.4

**Use of horizontal (directional)/
multi-bore wells in exploration activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	5	8.8	8.8	8.8
2	11	19.3	19.3	28.1
3	14	24.6	24.6	52.6
4	15	26.3	26.3	78.9
5	12	21.1	21.1	100.0
Total	57	100.0	100.0	

Table 6A.5

**Use of sustainable development
environmental technologies in exploration activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	5	8.8	8.8	8.8
2	10	17.5	17.5	26.3
3	19	33.3	33.3	59.6
4	16	28.1	28.1	87.7
5	7	12.3	12.3	100.0
Total	57	100.0	100.0	

Table 6A.6

**Use of 3D-4D and other advanced
seismic technologies in development activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	8	12.5	12.5	12.5
2	2	3.1	3.1	15.6
3	8	12.5	12.5	28.1
4	21	32.8	32.8	60.9
5	25	39.1	39.1	100.0
Total	64	100.0	100.0	

Table 6A.7

**Use of horizontal directional/
multi-bore wells in development activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	4	6.3	6.3	6.3
2	13	20.3	20.3	26.6
3	13	20.3	20.3	46.9
4	14	21.9	21.9	68.8
5	20	31.3	31.3	100.0
Total	64	100.0	100.0	

Table 6A.8

**Use of sustainable development &
environmental technologies in development activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	5	7.8	7.8	7.8
2	14	21.9	21.9	29.7
3	16	25.0	25.0	54.7
4	23	35.9	35.9	90.6
5	6	9.4	9.4	100.0
Total	64	100.0	100.0	

Table 6A.9

Use of 3D-4D seismic in production activities

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	22	34.9	34.9	34.9
2	6	9.5	9.5	44.4
3	9	14.3	14.3	58.7
4	15	23.8	23.8	82.5
5	11	17.5	17.5	100.0
Total	63	100.0	100.0	

Table 6A.10

Use of horizontal wells in production activities

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	6	9.5	9.5	9.5
2	16	25.4	25.4	34.9
3	14	22.2	22.2	57.1
4	14	22.2	22.2	79.4
5	13	20.6	20.6	100.0
Total	63	100.0	100.0	

Table 6A.11

**Use of advanced field recovery technology
in production activities in production activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	6	9.5	9.5	9.5
2	10	15.9	15.9	25.4
3	17	27.0	27.0	52.4
4	22	34.9	34.9	87.3
5	8	12.7	12.7	100.0
Total	63	100.0	100.0	

Table 6A.12

**Use of oil sands recovery processes
in production activities (e.g., SAGD)**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	46	73.0	73.0	73.0
2	2	3.2	3.2	76.2
4	6	9.5	9.5	85.7
5	9	14.3	14.3	100.0
Total	63	100.0	100.0	

Table 6A.13

**Use of transportation and transshipment
technologies in production activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	21	33.3	33.3	33.3
2	22	34.9	34.9	68.3
3	15	23.8	23.8	92.1
4	4	6.3	6.3	98.4
5	1	1.6	1.6	100.0
Total	63	100.0	100.0	

Table 6A.14

**Use of sustainable development and
environmental technologies in production activities**

Level of Importance	Frequency	Percent of Sample	Valid Percent	Cumulative Percent
1	7	11.1	11.1	11.1
2	15	23.8	23.8	34.9
3	17	27.0	27.0	61.9
4	18	28.6	28.6	90.5
5	6	9.5	9.5	100.0
Total	63	100.0	100.0	

CHAPTER 7

INFERENTIAL DATA ANALYSES

This chapter examines the drivers of innovation using principal component and regression analyses. Further, it examines the impact of major technologies on industry performance at all three phases of activity – exploration, production, and development – through descriptive and regression analyses. Comments received from industry experts during the course of this study are also included.

7.1 Drivers of Innovation – Principal Component Analysis

Principal component analysis (PCA) is used to further examine the 20 factors that drive firms to innovate. Given the large number of drivers and recognizing that many of them might be correlated, PCA was run, using SPSS, to reduce the number of factors. PCA is a variable reduction scheme that indicates how variables cluster or hang together (Stevens, 1992; Grandon and Pearson, 2004). The objective of PCA is to reduce the dimensionality of the data set – it involves a procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables that are called principal components.²⁶ The conceptual framework, discussed earlier, includes 20 drivers of innovation.

²⁶ Factor analysis is the other basic data reduction method but is relatively less simple than Principal Component Analysis. Both methods yield similar results (Stevens, 1992).

Using the Kaiser Eigen Values criterion, four factors were extracted accounting for 63.2 percent of the variance as shown in Table 7.1 The variance of the 20 components adds up to 100 percent.

Table 7.1

Total Variance Explained (1)

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.529	37.644	37.644	7.529	37.644	37.644	3.582	17.909	17.909
2	2.355	11.775	49.419	2.355	11.775	49.419	3.326	16.630	34.539
3	1.468	7.338	56.757	1.468	7.338	56.757	2.956	14.782	49.320
4	1.293	6.463	63.220	1.293	6.463	63.220	2.780	13.900	63.220
5	1.242	6.209	69.429						
6	.863	4.313	73.741						
7	.750	3.751	77.492						
8	.733	3.667	81.159						
9	.615	3.077	84.236						
10	.587	2.936	87.172						
11	.466	2.329	89.501						
12	.444	2.218	91.719						
13	.397	1.984	93.703						
14	.276	1.382	95.085						
15	.253	1.264	96.349						
16	.199	.993	97.343						
17	.168	.840	98.182						
18	.146	.731	98.913						
19	.115	.575	99.488						
20	.102	.512	100.000						

(1) Extraction Method: Principal Component Analysis.

Hair, *et al.*, (1998) provide guidelines for identifying significant factor analysis based on size of the sample, a .05 significance level (alpha), and a power level of 80 percent. A factor loading of .60 is considered as the cut off for this analysis; it is estimated from the guide provided by Hair, *et al.*, (1998) based on sample sizes. Figure 7.1 shows the scree plot of the

variables. The scree plot is used to identify the number of factors that can be extracted before the amount of unique variance begins to dominate the common variance structure. Although all the factors contain some unique variance, the amount of unique variance is higher with respect to the later than earlier factors. The scree plot supports using four factors because the breakout point occurs at the fifth Eigen value.

Figure 7.1

Scree Plot

Results obtained from the rotated component matrix are sorted and provided in Table 7.2. It shows the clustering of the various drivers of innovation. A total of 14 variables were selected and loaded clearly on the four constructs (shown bolded in Table 7.2).

Table 7.2
Clustering Drivers of Innovation Results of the Rotated Component Matrix ⁽¹⁾

Constructs	Drivers that loaded	Component			
		1	2	3	4
1. Performance	Reducing unit development costs	.704			
	Reducing unit operating costs	.760			
	Increasing productive capacity	.776			
	Increasing recovery factors	.636			
2. Market Environment	Responding to world crude price fluctuations		.832		
	Responding to natural gas price fluctuations		.798		
	Responding to supply demand conditions		.681		
	Improving market shares		.747		
3. Geologic Resources	Improving success ratios			.801	
	Improving targeting oil and gas reserves			.761	
	Reducing unit exploration costs			.711	
4. Environment Preservation	Reducing greenhouse gas emissions				.807
	Reducing environmental impacts				.852
	Meeting environmental regulations				.631
Drivers that did not load (values less than 0.60). ⁽²⁾ Their highest values and relevant constructs are provided (opposite)	Reducing unit replacement cost – .532 (Construct no.3) Reducing unit supply cost – .598 (Construct no. 1) Increasing productivity – .495 (Construct no.1) Reducing transportation and transshipment – .452 (Construct no.1) Proximity to reflect synergy – .584 (Construct no. 4) Improving community relations – .478 (Construct No.2)				

(1) Extraction Method: Principal Component Analysis.

(2) It is assumed that the variability of these drivers is captured among the four components.

Figure 7.2 shows the four constructs of the drivers of innovation – performance, market environment, geological resources, and environment preservation.

Figure 7.2: Illustrative Model Framework

As noted in Chapter 1, to provide a broader understanding of innovation in the upstream sector, the roles of collaboration and government are examined. The constructs for collaboration and government are introduced into the equation for estimation. But before this was done the following steps were taken. First, Cronbach Alphas for the set of variables in each of the four constructs, and the variables related to collaboration in question 8 (b) of the questionnaire and the variables related to government in question 9 of the questionnaire are estimated. Cronbach Alpha is a measure of reliability or internal consistency, the degree to which responses are consistent across the items within a single measure. According to Kline (2005), the most commonly reported estimate of reliability is Cronbach's coefficient alpha (α). The value ranges from 0 to 1. The Cronbach Alpha will generally increase when

correlations between items increase.²⁷ If internal consistency is low, the content of the items may be heterogeneous. Values of .60 and .70 range are considered the lower level of acceptability. Table 7.3 provides the Cronbach Alphas for the four constructs plus the two new constructs reflecting collaboration and government. The estimates suggest that the variables are highly correlated in each construct, considering that the values of the Cronbach Alpha exceed 0.6 in all cases.

Table 7.3

Factor Loadings and Cronbach Alphas

Variable Number	Factor Loadings	Variable Name	Cronbach Alpha
1	Performance	PERFOR	.805
2	Market Environment	MKTENVF	.846
3	Geologic Resources	GEORES	.777
4	Environment Preservation	ENVF	.814
5	Collaboration	COLNEW	.720
6	Government	GOVSUP	.812

²⁷ See Cooper (1995), Cronbach (1951) and Allen, M.J., and Yen, W. M (2002) for a discussion on the measure of Cronbach Alpha. Cronbach's α is defined as:

$$\frac{N}{N-1} \left(\frac{\sigma_X^2 - \sum_{i=1}^N \sigma_{Y_i}^2}{\sigma_X^2} \right),$$

where N is equal to the number of components (items), σ_X^2 is the variance of the observed total test scores, and $\sigma_{Y_i}^2$ is the variance of component i for person y . Alternatively, the standardized Cronbach's α can also be defined as:

$$\alpha = \frac{N \cdot \bar{r}}{(1 + (N-1) \cdot \bar{r})}$$

where N is the number of components (items) and $\bar{r}$ is the average of all Pearson correlation coefficients between the components.

Figure 7.3 shows collaboration and government added to the other four constructs to examine their influence on innovation.

Figure 7.3: Conceptual Constructs of Innovation Drivers With Collaboration and Government Influence

In order to further analyze the data, the normality of each construct was also examined by looking at the normality curve and histograms of the frequencies of the data, the skewness and the Kurtosis values, and box plots and de-trend plots. The histograms of the constructs which are included at the end of this chapter show that:

- the performance construct (PERFOR) appears somewhat skewed to the right – suggesting the higher emphasis being placed on cost and productive capacity (Figure 7A.1);

- the market environment construct (MKTENVF) is skewed to the left – indicating less emphasis on market prices and demand / supply conditions in determining innovation decisions (Figure 7A.2);
- the geologic resources construct (GEORES) is somewhat skewed to the right – highlighting the importance of factors such as improving success ratios and targeting oil and reserves, to innovation investment decisions (Figure 7A.3);
- the environment preservation construct (ENVF) seems fairly normally distributed with average importance being placed on innovation decisions (Figure 7A.4);
- the collaboration construct (COLNEW) is skewed to the left – suggesting less emphasis on collaboration (Figure 7A.5); and
- the government support construct (GOVSUP) is skewed to the left – indicating less importance of this construct (Figure 7A.6).

Overall, there is some skewness in the constructs. It should be recognized, however, that it is almost impossible to find data that are exactly normally distributed (Noursis, 1995). Of greater relevance is the normality of residuals when these constructs are used in regression analyses.

7.2 Correlation and Regression Analysis

Table 7.4 shows the variable name of each proxy for each construct, which was estimated by taking the average of the responses of the drivers that load on the constructs. Similarly, for collaboration and the government constructs, averages of the relevant responses were taken.

Table 7.4

Definition of Variables Used in Regression Analysis

Variable Number	Variable Name	Description of Variables
1	INNOVF	The average of the three modes of innovation (acquisition of advanced machinery and equipment, advanced processes, and other external knowledge) of all respondents.
2	PERFOR	The average of the following four variables which load on the <i>performance</i> construct: reducing unit development costs; reducing unit operating costs; increasing productive capacity; and increasing recovery factors of all respondents.
3	MKTENVF	The average of the following four factors that load on the <i>Market Environment</i> construct: responding to world crude prices fluctuations; responding to natural gas prices fluctuations; responding to supply demand conditions; and improving market shares of all respondents.
4	GEORES	The average of the following three factors that load on the <i>Geologic Resources</i> construct: reducing unit exploration costs; improving success ratios; and improving targeting oil and gas reserves of all respondents.
5	ENVF	The average of the following three variables that load on the <i>Environment Preservation</i> construct: reducing greenhouse gas emissions; reducing environmental impacts; and meeting environmental regulations of all respondents.
6	COLNEW	The average of firms' collaboration with the following organizations: universities and colleges, federal government laboratories, research institutes, provincial and territorial governments, competitors, suppliers of equipment and materials, and foreign companies (as per Q. 8 part b of the questionnaire) of all respondents.
7	GOVSUP	The average of the following variables were used to develop the variable for government support: R&D tax credits (SR&ED), government technology support programs, employee exchange programs, government fiscal frameworks, partnerships with governments, and government support for training of all respondents.

7.2.1 Correlation Analysis

Table 7.5 shows the correlation coefficients of innovation with the four constructs of the drivers of innovation in the sector derived from factor analysis. Innovation is estimated to be the average of the three variables: i) acquisition of advanced modern equipment; ii) acquisition of advanced processes; and iii) acquisition of other external knowledge (external R&D, patents, inventions licences, packaged software, trademarks, non-patented knowledge, disclosures, etc.).

Table 7.5

Correlation Coefficients of Driver Constructs

	INNOVF (Innovation)	PERFOR (Performance)	MKTENVF (Market Environment)	GEORESF (Geologic Resources)	ENVF (Environment Preservation)
INNOVF	1	.436(*)	.163	.396(*)	.523(*)
PERFOR	.436(*)	1	.432(*)	.459(*)	.464(*)
MKTENVF	.163	.432(*)	1	.273	.497(*)
GEORESF	.396(*)	.459(*)	.273	1	.361(*)
ENVF	.523(*)	.464(*)	.497(*)	.361(*)	1

* Correlation is significant at the 0.01 level (2-tailed).

- The results suggest that innovation decisions to acquire advanced machinery and equipment, advanced processes, and other external knowledge are related to:
 - environmental concerns such as reducing greenhouse gas emissions (e.g., to meet the Kyoto targets), reducing environmental impacts (e.g., on terrain, flora, and fauna), and meeting environmental regulations;

- reducing unit development costs, increasing productive capacity, and increasing recovery factors.
- improving success ratios and improving targeting oil and gas reserves (but to a lesser extent than the environmental and regulatory construct) but not to market environment factors, including responding to crude oil and natural gas price fluctuations, demand /supply conditions, and improving market shares.

Many companies make their plans based on internal price forecasts with some long term price stability built in, erring more on the side of caution. With respect to production, it is recognized both in Canadian and U.S. industry that oil can be produced at a significantly lower price in OPEC countries. Firms can readily sell their output of oil (particularly conventional light and synthetic oil) and natural gas. In the case of oil, domestic supplies can back out imports into both the U.S. and Canadian markets. In terms of natural gas, the market can absorb both U.S. and Canadian supplies with excess production going to storage in any particular year. This is not usually significant.

- The estimated coefficients show that there is reasonable correlation among the performance construct (PERFOR), the market construct (MKTENVF), the geological reserves construct (GEORES), and the environment preservation construct (ENVF). As well, the correlation coefficients are also in the same order of magnitude as can be seen in Table 7.5. The results suggest that reducing unit development and operating costs and increasing productive factors are related to:

- market conditions, which include responding to crude oil and natural gas price fluctuations, demand /supply conditions, and improving market shares;
 - improving success ratios and improving targeting oil and gas reserves; and
 - reducing greenhouse gas emissions, reducing environmental impacts, and meeting environmental regulations.
- The market conditions that include responding to crude oil and natural gas price fluctuations, demand /supply conditions, and improving market shares are correlated with such factors as reducing greenhouse gas emissions (e.g., to meet the Kyoto targets), reducing environmental impact (e.g., terrain, flora and fauna), and meeting environmental regulations.

The correlation coefficient of the market conditions construct and innovation is weak. This suggests that factors – such as rapid changes in world prices, and natural gas prices and demand and supply had a limited impact on the innovation decision of firms in the upstream sector. It is normally the case that when prices are high firms can go after higher cost reserves and projects and still remain profitable. A typical saying in the industry is that very high prices can lead to drilling of moose pastures. A typical comment received from industry analysts is that super depletion allowances coupled with the high prices in the late 1970s and early 1980s also caused such behavior. It is not surprising, also, that the low level of correlation with market conditions and the geological conditions variables – such as lower exploration costs, success ratios, and targeting oil and gas – are weak. Given the high crude oil and natural gas prices that have prevailed over the past few years it is possible that the

industry has been less cautious in seeking to improve success ratios and targeting oil and gas reserves. A possible explanation for the results is that the sample size is small (and becomes further reduced when the collaboration construct is introduced, given that only two thirds of the sample is used).

7.2.2 Regression Analyses

To examine the impact of the four constructs (performance, market environment, geological/resources, environment preservation), collaboration, and government influence on innovation, a multiple regression model was estimated. The functional form of the multiple regression equation containing all six constructs is:

$$Y_i = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + E_i$$

Where:

Y_i is the dependent variable: innovation (INNOVF), as described in Table 7.4, and B_1 to B_4 are the four constructs. B_5 and B_6 are the collaboration and government variables respectively that are also described in Table 7.4.

The estimated equation is:

$$\text{INNOVF} = B_0 + B_1 \cdot \text{PERFOR} + B_2 \cdot \text{MKTENVF} + B_3 \cdot \text{GEORESF} + B_4 \cdot \text{ENVF} + B_5 \cdot \text{COLNEW} + B_6 \cdot \text{GOVSUP} + e$$

The equation shows the relationship between innovation and all six explanatory variables.

The results of the estimated equation are presented in Table 7.6.

Table 7.6

Regression Coefficients of Full Equation

EQ:1	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
R ² = .458							
(Constant)	.704	.764		.922	.362		
PERFOR	.099	.176	.080	.561	.578	.725	1.379
MKTENVF	-.126	.123	-.145	-1.023	.313	.726	1.377
GEORES	.166	.116	.193	1.431	.161	.802	1.246
ENVF	.568	.142	.602	4.013	.000	.651	1.535
COLNEW	-.081	.200	-.060	-.405	.688	.665	1.503
GOVSUP	.128	.165	.114	.778	.441	.680	1.471

a. Dependent Variable: INNOVF

The equation provides a reasonably good fit to the data with an R-Square of .458. ENVF, the environment preservation construct variable, is highly significant. The only other variable with some level of significance is the geologic variable (GEORES), albeit this is only at the .16 level. The results suggest that there are some levels of collinearity (although not serious) among variables given the VIF values of over one, as shown in Table 7.6. VIF values of over ten suggest serious problems with multicollinearity. Multicollinearity can render variables to be insignificant and the equation to be unstable.

Figure 7.4 All Constructs – Full Equation Histogram

The results shown in Figure 7.4 suggest that the residuals are close to being normally distributed. To correct for multicollinearity, a *Stepwise* procedure was run for the full equation.²⁸ The *Stepwise* procedure involves determining the least useful predictors. The equation selected through this procedure shows the environment preservation construct as highly significant at the .001 level. The other three constructs and the collaboration and government variables are also insignificant.

²⁸ Like in the full equation, the number of observations used in this equation is 44 to match where collaborative agreements did take place.

Table 7.7

Regression Coefficients of Stepwise Procedure of Full Equation

EQ7 – Stepwise Regression	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
R ² =.397 (Constant)	1.439	.408		3.524	.001
ENVF	.595	.113	.630	5.264	.000

a. Dependent Variable: INNOVF
(*) DF = 42

Table 7.7 shows the estimates of the coefficients of the *Stepwise* procedure and Figure 7.5 shows the residuals of the *Stepwise* equation. These residuals appear to be fairly normally distributed.

Figure 7.5 Stepwise Equation Histogram

These results suggest that environmental concerns such as reducing environmental impact (e.g., terrain, flora, and fauna), and meeting environmental regulations are important in explaining variance in investment in innovation.

7.3 Impact of Technology on Performance

This section examines the impact of technology on key performance indicators in the exploration, development, and production phases in the upstream petroleum sector. Firms were asked to rate the level of impact on specific performance indicators on a scale of 1 to 5 where: 1 is not at all important, 2 somewhat important, 3 reasonably important, 4 substantially important, and 5 extensively important. The questions related to the impact of the following technologies on exploration, development, and production activities. The application of technologies with respect to each phase in the upstream sector is shown in Table 7.8.

Table 7.8

Application of Technologies in Specific Activity

Technologies	Exploration	Development	Production
3D seismic and 4D seismic and other advanced seismic technologies	✓	✓	✓
Horizontal (directional) multi bore wells	✓	✓	✓
Advanced field recovery technology (e.g., enhanced oil recovery methods – water floods, CO ₂ injections, advanced pumping and production techniques)	-	-	✓
Advanced oil sands recovery processes (e.g., SAGD)	-	-	✓
Transportation and transshipment technology	-	-	✓
Sustainable development/ environmental technologies (e.g., for reducing CO ₂ emissions, natural gas flaring, and oil spillage, etc.)	✓	✓	✓

Note: ✓ – indicates where their applications are relevant and where their impacts were considered.

The performance parameters for each of the six technologies in each phase of operation that are examined are shown Table 7A.1 at the end of this chapter. Table 7A.2, also at the end of this chapter, shows a summary of the performance parameters that are relevant for exploration, development, and production. The impact of specific technologies was assessed through estimating the means of the responses, and of the performance parameter with respect to each technology for each performance parameter in each phase of operation. Cronbach Alphas and regression analyses are used to examine the impact of technology on performance. Finally, the comments received from companies are presented.

As noted in Chapter 2, there is interest on firm size in the innovation literature. The results with respect to firm size have been mixed. The model framework presented in Chapter 4 does not explicitly seek to capture firm size. This study, however, asks questions about firm size to obtain a profile of the respondents and to gauge the representativeness of the sample. For the upstream sector, it is recognized that large and integrated companies are mainly involved in major projects – such as oil sands and frontier developments while – small firms have a tendency to be involved more in conventional activity. To get a sense of whether technology had a different impact on performance by firm size, the performance impact is also examined by the three firm size groupings (discussed earlier): small, medium, and large and integrated companies. It is expected that this type of analysis may shed some light on the firm size and innovation issue.

7.3.1 Impact of Major Technologies in Exploration

This section will provide a discussion of the impact of technology based on the results obtained from estimating the mean of the responses with respect to each technology in exploration (see Figures 7A.7 to 7A.9 at the end of this chapter). Companies were asked about the impact of 3D/4D seismic, horizontal wells, and sustainable development technologies on several performance indicators in the exploration activity of their operations.

i) *Advanced Seismic Technology 3/4D*

The six performance parameters examined with respect to 3D/4D seismic are:

- reduce unit exploration costs;
- reduce unit replacement costs;
- increase productive capacity (e.g., finding new reserves);
- increase productivity;
- improve targeting of oil and gas reserve deposits; and
- improve success ratios.

The means of company responses on the above performance parameters are presented in Figure 7 A.7 at the end of this chapter. The results show that targeting oil and gas reserves deposits followed by improving success ratios experienced the highest impact due to the use of 3D/4D and other advanced seismic technologies. Overall, all performance parameters showed above average impact due to the application of 3D/4D seismic technology. This demonstrates the overall importance of this technology in exploration activity and its

significance for a firm in reducing risks associated with exploration and the ability to isolate oil and gas reserves for future development.

ii) ***Horizontal Wells and Multi-bore in Exploration***

The six performance parameters examined with respect to horizontal wells are:

- reduce replacement costs;
- increase productive capacity (e.g., finding accessing new reserves);
- increase productivity;
- improve targeting of oil and gas reserve deposits;
- improve success ratios; and
- increase recovery factors.

The estimated mean values show that the greatest impact of horizontal wells is with respect to productivity, recovery factors and productive capacity (Figure 7 A.8 at the end of this chapter). The impact of the improvement in success ratios, targeting oil and gas reserves, and reducing replacement costs are not as important. This result is interesting in that it demonstrates that the impact of this technology has less effect for reducing exploration risks.

iii) ***Sustainable Development and Environmental Technologies***

The five performance parameters examined with respect to sustainable development are:

- reduce environmental impact;
- reduce greenhouse gas emissions;
- improve community relations;
- increase market shares; and

- better meet environmental regulations / standards.

The estimated mean values show that sustainable development technologies had the greatest impact on meeting environmental regulations/standards, reducing environmental impact, and improving market shares (see Figure 7 A.9 at this end of the chapter). As noted earlier, environmental regulation was found to be a key driver of innovation in the upstream sector and it is noteworthy that sustainable development technologies have had the greatest impact in terms of meeting environmental regulations. Notable also is that reducing greenhouse gas emissions is below reasonably important in spite of the fact that reducing greenhouse gas emissions is a key public policy concern.

7.3.2 Impact of Major Technologies in Development

This section will provide a discussion of the impact of technology based on the results obtained from estimating the mean of the responses with respect to each technology in development activity (see Figures 7A.10 to 7A 12). As in the exploration phase of the industry, firms were asked about the impact of 3D/4D seismic, horizontal wells, and sustainable development technologies on their performance.

i) ***3D (and 4D) and Other Advanced Seismic Technologies***

The six performance parameters examined with respect to 3D/4D seismic and other advanced seismic technologies in development activities are:

- reduce unit development costs;
- reduce unit replacement costs;

- increase productive capacity (e.g., developing new reserves);
- increase productivity;
- improve targeting of oil and gas reserve deposits; and
- improve success ratios.

The mean values show that 3D/4D and other advanced seismic technology have the most impact in reducing development costs, improving success ratios, and targeting oil and gas reserves. This demonstrates that through the use of 3D/4D, companies are better able to map and study the reservoirs for development and hence are capable of improving success. It is not surprising, therefore, that development costs have been more than reasonably impacted through the use of 3D/4D seismic.

ii) *Horizontal (Directional) Wells*

The six performance parameters examined with respect to horizontal wells are:

- reduce unit development costs;
- reduce unit replacement costs;
- increase productive capacity (e.g., developing new reserves);
- increase productivity;
- improve targeting of oil and gas reserve deposits; and
- increase recovery factors.

The mean values for the six performance parameters shows that horizontal wells have a significant impact on performance. The greatest impact is with respect to increasing recovery factors, productivity, and productive capacity. It has also favorably impacted the reduction in development costs, replacement costs, and targeting of reserves.

iii) ***Sustainable Development and Environmental Technologies***

The five performance parameters examined with respect to sustainable development and environmental technologies are:

- reduce environmental impact;
- reduce greenhouse gas emissions;
- improve community relationships;
- increase market shares; and
- better meet environmental regulations / standards.

The mean of the responses of sustainable development technologies with respect to the performance parameters shows the greatest effect is on reducing environmental impact and reducing greenhouse gas emissions as shown in Figure 7 A.7 at this end of the chapter. Improving community relationship also shows a reasonable impact. This is interesting in that firms stress the importance of building good community relationships through the use of sustainable development technologies.

7.3.3 Impact of Major Technologies in Production

This section will provide a discussion of the impact of technology based on the results obtained from estimating the mean of the responses with respect to each technology in development activity (see Figures 7A.13 to 7 A.18 at the end of this chapter).

i) ***3D/4D Seismic and other Advanced Seismic Technologies***

The following four performance parameters examined with respect to 3D/4D seismic and other advanced seismic technologies in production activities are:

- reduce unit supply price;
- increase productive capacity (e.g., developing new reserves);
- increase productivity; and
- improve targeting of oil and gas reserve deposits.

The mean values show that 3D/4D and other advanced seismic technologies have the highest impact on improving the targeting of oil and gas reserves. This is considered important, as firms can manage production to better meet market demands.

ii) ***Horizontal (Directional) Wells***

The eight performance parameters examined with respect to horizontal wells in development activity are:

- reduce unit supply price;

- reduce unit operating costs;
- increase productive capacity;
- increase productivity;
- improve targeting of oil and gas reserve deposits;
- improve producer netbacks;
- manage production for market conditions; and
- increase recovery factors.

Horizontal wells were found to have the highest impact on productivity, recovery factors, and productive capacity. The overall result is consistent with the view that horizontal wells allow for the reservoirs to be drained faster as they make greater contact with the reservoir than a conventional vertical well. Hence, productivity and productive capacity can be improved. Productive capacity also improves by the ability of horizontal wells to tap into reservoirs and parts of a reservoir because of geology, geography, or environmentally sensitive areas that may not be easily accessible by a vertical well.

iii) *Advanced Field Recovery Technology*

The six performance parameters examined with respect to advanced field recovery technology are:

- reduce unit supply price;
- reduce unit operating costs;
- increase productive capacity;

- increase productivity;
- improve producer netbacks; and
- improve market shares.

The means of the responses show that field recovery technology had the highest impact with respect to increasing productivity, followed by the increase in productive capacity. Given the oil and natural gas prices in recent years, it is likely that companies with the use of advanced technologies are going after oil and natural gas still left in the reservoirs.

iv) ***Oil Sands Technology - (e.g., SAGD)***

The six performance parameters examined with respect to advanced oil sands recovery are:

- reduce unit supply price;
- reduce unit operating costs;
- increase productive capacity;
- increase productivity;
- improve producer netbacks; and
- improve market shares.

The impact of technology was highest with respect to productivity, followed by productive capacity, improving market shares, and reducing operating costs. Further, oil sands technology is also impacting favorably on supply price and producer netbacks. The industry view is that operating costs have been reduced substantially as a result of the application of technology. The application of oil sands technology has significant implications for Canada's oil supply and for meeting increasing demand in the U.S. As

noted in Chapter 3, a large number of oil sands projects are being brought on stream as well a large number of expansions and new projects have been announced to meet growing demands. The cost of producing bitumen from greenfield projects is currently around U.S. \$16 per barrel. It is highly sensitive to the steam oil ratio. The cost of producing oil from an integrated mining project is about \$33 per barrel.

iv) ***Transportation and Transshipment Technology***

The three performance parameters examined with respect to transportation and transshipment technology are:

- reduce unit transportation costs;
- reduce environmental impact; and
- increase productive capacity (improve viability of new projects).

The mean values show that the impact of transportation and transshipment technology for reducing transportation costs, reducing environmental impact, and increasing productive capacity are just slightly above somewhat important. It should be noted that although transportation is important for gathering and transshipping crude and natural gas, it is only a small part of the overall price of oil and natural gas. Thus the lack of a substantial impact of costs may not limit production significantly.

vi) ***Sustainable Development and Environmental Technologies***

The five performance parameters examined with respect to sustainable development and environmental technologies are:

- reduce environmental impact;
- reduce greenhouse gas emissions;
- improve community relationships;
- increase market shares; and
- better meet environmental regulations / standards.

The greatest impact of sustainable development technology was experienced in reducing environmental impacts and meeting environmental regulations and standards, followed by improving community relations. Better meeting environmental regulations was seen earlier to be a key driver of innovation. The impact of technology demonstrates that firms are using sustainable development technologies to better meet environmental regulations reducing environmental impacts.

Overall, the analysis showed that the various technologies examined in all phases of the industry had significant impacts on performance on individual parameters. It was found that 3D/4D technology plays an important role in improving success ratios and targeting oil and gas reserves. Horizontal wells are key to increasing productivity, productive capacity and recovery factors. Sustainable development technologies are crucial for meeting environmental regulations and reducing environmental impacts. The impact of transportation and transshipment technology had only limited impact on performance. Oil sands technologies are important for increasing productivity and productive capacity. The results also suggest that large and integrated firms have an advantage in the use of 3D/4D seismic and horizontal wells, and advanced field recovery technologies.

7.3.4 Cronbach Alpha Tests

Cronbach Alphas were estimated for each set of performance variables with respect to specific technologies for each phase of operation – exploration, development, and production – to obtain a sense of the relationships of these variables (Table 7.9). These high values of Cronbach Alphas indicate that the performance indicators for each technology in each phase of operation are highly correlated.

Table 7.9

Impact of Technology in Each Phase of Operation: Cronbach Alpha

Use of Specific Technologies	Phase of Operation	Cronbach Alphas of Performance Indicators
Use of 3D/4D and other advanced seismic technology	Exploration	.973
Use of horizontal and multi-bore wells	Exploration	.936
Use of sustainable development technologies	Exploration	.889
Use of 3D/4D and other advanced seismic technology	Development	.949
Use of horizontal and multi-bore wells	Development	.956
Use of sustainable development technologies	Development	.899
Use of 3D/4D and other advanced seismic technology	Production	.949
Use of horizontal and multi-bore wells	Production	.957
Use of advanced field recovery technologies	Production	.942
Use of oil sands recovery process in production activities (e.g., SAGD) technology	Production	.980
Use of transportation and transshipment technology	Production	.941
Use of sustainable development technologies	Production	.922

The averages of the performance parameters with respect to each technology in each phase of operation were estimated. This resulted in twelve single performance variables. Given the high level of association of each set of variables (based on the high value of the Cronbach Alpha), it could be considered reasonable to develop such single estimates. Given that three technologies are investigated in exploration, three in development, and six in production on performance, this results in twelve variables. The variables are shown in Table 7.10. These variables are used as dependent variables in the regression analyses.

7.3.5 Regression Analyses

Twelve simple regression equations were used to examine the impact of technology on performance. The explanatory variables are the technologies with respect to each phase of operation. The functional form of the equation is a modified version of the equation presented in Section 7.2 which has more than one explanatory variable. The results of the twelve equations are summarized in Table 7.10. The equations are described in Table 7A.3 at the end of this chapter. Detailed results of the equations are also provided at the end of this chapter – Tables 7A.5 to 7A.16.

Table 7.10

**Estimated Results of the Equations of the Impact Technology in
Each Phase of Operation (Exploration, Development and Production)**

EQ. Nos.	Dependent Variables - Performance	Coefficients and significance	R-Square (R ²)	Independent Variables	Phase of Operation
1	SEIEXPL - Average performance variable with respect to 3D-4D seismic	.847 (***) (.036)	.893	Use of 3D/4D and other advanced seismic technology	Exploration
2	HOREXPL – Average performance variable with respect to horizontal wells	.672 (***) (.062)	.640	Use of horizontal and multi-bore wells	Exploration
3	SUSDIMP – Average performance variable with respect to sustainable development technologies	.678 (***) (.057)	.684	Use of sustainable development technologies	Exploration
4	SEIDEVIM – Average performance variable with respect to 3D/4D seismic	.817 (***) (.054)	.776	Use of 3D/4D and other advanced seismic technology	Development
5	HORIDEV - Average performance variable with respect to Horizontal wells	.593 (***) (.080)	.467	Use of horizontal and multi-bore wells	Development
6	SUSTIM - Average performance variable with respect to sustainable development technologies	.567 (***) (.083)	.415	Use of sustainable development technologies	Development
7	SEISPROD – Average performance variable with respect to 3D/4D seismic	.584 (***) (.080)	.469	Use of 3D/4D and other advanced seismic technology	Production
8	HORIZIMP – Average performance variable with respect to horizontal wells	.674 (***) (.069)	.589	Use of horizontal and multi-bore wells	Production
9	AdvfieldREC – Average performance variable with respect to advanced field recovery technology	.584 (**) (.089)	.416	Use of advanced field recovery technology	Production
10	SADGDIM – Average performance variable with respect oil sands technology	.618 (***) (.203)	.381	Use of oil sands recovery process in production activities (e.g., SAGD) technology	Production
11	TRANS - Average performance variable with respect transportation and transshipment technology	.653 (***) (.103)	.378	Transportation and transshipment technology	Production
12	SSD - Average performance variable with respect sustainable development technologies	.576 (***) (.076)	.465	Sustainable development technologies	Production

Notes:

1. Column 1 shows the names of the average performance variables for each technology in each phase of operation.
2. (*) – coefficients are significant at the .05 level; (**) coefficients are significant at the .01 level; and (***) coefficients are significant at the .001 level. Standard errors of the coefficients are shown in parenthesis.
4. For SAGDIM (oil sands performance), only oil sands operators (17) are considered.

The results of the twelve estimated equations are fairly robust. The estimated coefficients show that the variables are highly significant and the equations fit the responses quite well. The R-Squares of the equations, which are equivalent to correlation coefficients, indicate that there is a close correlation between the application of the technologies and performance in the upstream sector. The use of 3D/4D seismic has the highest correlation with performance in exploration activity. In development activity, 3D/4D seismic also had the highest correlation coefficient with performance. In production activity, however, horizontal wells have the greatest impact on production.

7.3.6 Impact of Technology and Firms Size

Table 7.11 provides the mean values of the impacts of technology on the performance parameters in each phase of operation (exploration, development, and production) for each size category (large and integrated firms, medium, and small firms).

Table 7.11

**Mean Values of Performance Indicators in
Each Phase of Upstream Activity According to Firm Size**

	Firm Size	Performance Indicators	Group Size No. of Firms	Mean	Std. Deviation
E X P L O R A T I O N	Large and integrated	SEIEXPL	20	3.68333	1.01437
		HOREXPL	20	3.20833	.75292
		SUSDIMP	20	3.13000	.88324
	Medium	SEIEXPL	13	3.71795	.96077
		HOREXPL	13	2.33333	1.19412
		SUSDIMP	13	2.63077	.96556
	Small	SEIEXPL	24	3.20139	1.49474
		HOREXPL	24	3.00694	1.07618
		SUSDIMP	24	2.42500	.89698
57 Firms					
D E V E L O P M E N T	Large and integrated	SEIDEVIM	23	3.53623	1.05763
		HORIDEV	23	3.76812	.64613
		SUSTIM	23	3.27826	.77163
	Medium	SEIDEVIM	16	3.58333	1.14504
		HORIDEV	16	3.13542	1.37651
		SUSTIM	16	2.85000	.97843
	Small	SEIDEVIM	25	3.34000	1.39566
		HORIDEV	25	2.94000	1.15702
		SUSTIM	25	2.38400	.91090
64 Firms					
P R O D U C T I O N	Large and integrated	SEISPROD	24	2.88330	1.33699
		HORIZIMP	24	3.27083	.88132
		AdvfieldREC	24	2.87500	.89988
		SADGDIM (*)	(17)	3.19610	1.30202
		TRANS	24	2.55556	1.17817
		SSD	24	3.13333	1.03111
	Medium	SEISPROD	16	2.83750	1.47009
		HORIZIMP	16	3.05469	1.44407
		AdvfieldREC	16	2.93750	.95043
		SADGDIM (*)	(17)	3.19610	1.30202
		TRANS	16	2.12500	.97278
		SSD	16	2.85000	.93095
	Small	SEISPROD	23	2.44350	1.29468
		HORIZIMP	23	2.69565	1.07650
		AdvfieldREC	23	2.16667	1.04844
		SADGDIM (*)	(17)	3.19610	1.30202
		TRANS	23	2.01449	.94001
		SSD	23	2.32174	.79026
63 Firms					

Note: (*) Given the small number of companies involved in oil sands operations, statistics were computed for the group as a whole.

The three technologies common to exploration, development, and production are 3D/4D seismic, horizontal wells, and sustainable development technologies. In addition, advanced field recovery technology, transportation and transshipment technologies, and oil sands technology are relevant to the development phase. The mean values show that these six technologies had an impact across all group sizes in the industry. This is probably due to the fact that significant capital outlays are required for oil sands production.

To obtain a better understanding of the difference in impacts of other technologies, means difference tests were carried out using the *Independent Samples Test*; these are summarized in Table 7.12.

Table 7.12
Size Impact of Technologies
Independent Samples Test for Difference in Means – Levene Test ⁽¹⁾

	Large and Integrated vs. Small	Large and Integrated vs. Medium	Medium vs. Small
Exploration	SEIEXPL (.01) HOREXPL (.05)	HOREXPL (.005)	SEIEXPL (.05)
Development	HORIDEV (.01)	HORIDEV (.0001)	–
Production	AdvfieldREC (.05)	HORIZIMP (.01)	–

⁽¹⁾ Values of level of significance are rounded and provided in parentheses.

The results suggest that the impact of 3D/4D seismic technologies is greater for large versus small firms, and medium versus small firms. A possible explanation could be that the leases and properties acquired by small firms may not be as prolific as those of large and integrated firms and medium-sized firms. This could reflect the lease bidding process as large firms can

outbid smaller firms for better and more expensive properties. As well, small firms acquire less productive properties from large and medium-sized firms. Another explanation could be with regards to the amount of investments small medium and large companies make in terms of data interpretation. The impact of horizontal wells for large and integrated firms exceeds that of medium-sized and small firms in exploration. Some of the same explanations may apply to the different impact on horizontal wells. Both 3D/4D seismic technologies and horizontal wells rely on significant expertise.

Advanced field recovery techniques have greater impact on large firms versus small firms. A possible explanation is that large firms are older and have access to some of the older large pools, which yield greater impact with respect to advanced field recovery techniques. Large and integrated firms can benefit from economies of scale. Small firm tend to acquire properties that have been “worked over” or are marginal and may not fit into the overall business strategy of large firms. Horizontal wells have greater impact for large and integrated firms over medium-sized firms. Some of the impact could be reservoir specific, particularly in heavy oil reservoirs in which the large companies are involved.

7.3.7 Comments Received from Industry Experts

Key comments by industry with respect to each technology and phase of operation are provided below. It should be recognized that the comments in one phase may straddle other phases and are not mutually exclusive.

i) ***Advanced Seismic Technology 3/4D – Exploration***

- 3D/4D seismic is extremely important in frontier oil exploration (north and offshore regions), where wells are very costly to drill. Avoiding dry holes can result in substantial savings (prevention of great losses). The extra money spent on 3D/4D seismic to undertake in-depth analysis and avoid sinking hundreds of millions of dollars in a dry hole is worthwhile.
- Big interests exist in oil rather than natural gas in the frontier regions given the high costs associated with transporting natural gas from these areas. 3D/4D seismic and other advanced seismic make it possible to better target oil and gas deposits and to decide whether to proceed with any type of activity.
- 3D/4D technologies are instrumental to making the big finds in offshore regions and for “deep water” exploration – the recent big find in the Gulf of Mexico is a case and point.
- 3D/4D seismic is not expected to yield big finds in conventional areas. Most of the giant oil pools on land probably have already been discovered; the new exploration frontiers are in the deep sea.

ii) ***Horizontal Wells and multi-bore – Exploration***

- Horizontal wells are very useful in terms of offshore areas where they are drilled from the main platform to reduce costs.

- The Hibernia oil project is a prime example where such technology, has had tremendous impact on cost savings. It is one of the largest offshore projects that uses directional/horizontal wells technology which has allowed for multiple wells to be “fanned out” from the same offshore production platform.
- In the case of existing production, horizontal wells are very useful to test and probe other horizons for hydrocarbons deposits to drill other step-out wells.
- Geography can sometimes inhibit access and horizontal wells are extremely convenient to tap into reserve basins that are inaccessible by vertical wells.
- Environmental considerations are important in the use of this technology as it could go under lakes to tap reserves as well as be used in other environmentally sensitive areas and help to meet environmental regulations.

iii) Sustainable development and environmental technologies – Exploration

- Stronger pipes, better drill bits, more energy-efficient equipment, best practices, and training are preventing blow-outs, and accidents, and reducing of emissions; and
- 3D/4D seismic combined with horizontal wells is having less invasive impact on the environment.

iv) 3D (and (4D) and other advanced seismic technologies – Development

- 3D/4D seismic and other seismic technologies are very useful in deciding how to develop the reservoirs, including the placement of wells, and deciding on the types of wells to be used.

- 3D/4D seismic technologies can map out the development of reservoirs over time.
- Advanced seismic (3D/4D) technologies were extremely helpful for planning exactly where the wells were to be placed in the Hibernia reservoirs to yield the best returns.

v) ***The application of Horizontal (Directional) Wells – Development Activity***

- Horizontal wells can be used in place of several vertical wells and the reservoirs can be drained much faster.
- Although more expensive than vertical wells, the cost savings exceed the costs of the wells.
- The skills required to drill these wells are very high. One company noted that “the precision is frequently within a metre over one kilometer stretch.”
- This technology combined with coiled tubing instead of the use of rigid pipes, can lead to significant flexibility in terms of set up and completing wells and re-entering existing wells.
- The time to set up and complete a well using coiled tubing has been significantly reduced. It was noted that companies can now complete about four shallow wells in one day, whereas not so long ago, one well used to take many days to complete.

vi) ***Sustainable Development and Environmental Technologies – Development Activity***

- Regulations from the AEUB, the NEB, and Environment Canada are important in ensuring that environmental regulations are met.

- Best practices as well improvements in valves, pipes, drill bits, fluids, and other materials have all been important in reducing greenhouse gas emissions and preserving the environment in exploration activity.

vii) ***3D/4D Seismic and other Advanced Seismic Technologies – Production Activity***

- The use of 3D/4D was considered quite important for monitoring the reservoirs over time and for assisting with production.
- This technology combined with horizontal wells can improve efficiency and result in a substantial impact on cost savings.

viii) ***Comments from Industry Experts – Development Activity***

- Horizontal wells are very versatile in the production process as they can be used to improve efficiency and as a sustainable development technology.
- Horizontal wells suck the oil out of the ground really quickly and this enables higher production and improves the rate of return.

ix) ***Advanced field recovery technology – Development Activity.***

- High prices have caused renewed interest in enhanced oil recovery, encouraging companies to go after oil left behind, to reexamine abandoned wells, and to improve the pressure of existing wells.

- One company noted that as much as 90 percent of heavy oil is left behind in reservoirs.
- CO₂ injection with respect to enhanced oil recovery is becoming of great interest to the industry. This is driven partly by economics but also by consideration to reduce greenhouse gas emissions.

ix) ***Oil sands technology - (e.g., SAGD) – Development Activity***

- SAGD has been a significant innovation for in-situ bitumen process and it has improved productivity and project economics above the huff and puff method.
- SAGD did not happen overnight but took many years and commitment to develop. As highlighted earlier, SAGD involves the use of two horizontal wells where steam is injected through one horizontal well (to heat the oil sands) and the reservoir is drained by the other horizontal well.
- Truck and shovel has led to significant improvements in flexibility over the “bucket and shovel.”
- “Crushing and grinding” or “emulsifying” of the oil sands and using hydro transport provides access to deposits as far as 10-40 kilometers from the plant. This process allows for partial separation before the oil sands get to the plant.
- Companies have been able to reduce oil sands operating cost from \$30/bbl to (\$12-14/bbl).
- The use of water, the high amount of energy, and the impact on the environment – particularly the high level of CO₂ and the tailings associated with production – are key challenges to the industry.

- To produce one barrel of oil from oil sands requires 5 barrels of water; this could turn into a major problem as aggressive development of oil sands takes place.
- Natural gas is used as the source of energy for combustion in the sector. A few companies noted that the equivalent of the Mackenzie Delta project can easily disappear because of the expansion of oil sands development.
- Companies are experimenting with different ways at looking at solving their energy needs. The Long Lake integrated bitumen upgrading project by OPTI Canada Inc. and Nexen Inc. represents the first implementation of a gasification project in conjunction with heavy oil recovery and upgrading project.
- The time may be appropriate to look at nuclear energy as a possible way to address energy requirements for oil sands development.
- Skills shortages are a key problem and the high cost of living is also proving challenging in attracting the right skill sets.

xi) ***Transportation and transshipment technology – Development Activity.***

- The improvements in pipes, materials, and valves are making a significant impact to the industry.
- Miniature computers and equipment can detect and repair leaks in a cost efficient and environmentally friendly manner.
- Transportation cost is, on average, small relative to overall unit price of a barrel of oil.

xii) ***Sustainable Development and Environmental Technologies – Development Activity***

- Environmental and safety regulations are taken very seriously.
- Building good relations with communities are important.
- Having procurement and employment policies that favor aboriginals are important.

Other General Comments

Four separate comments from three senior executives:

- As a large integrated company, it is difficult to capture everything.
- I attended Carleton University, hence the reason for filling out this questionnaire.
- If you were offered a job out here, think twice before accepting it because of the cost of living.
- I am willing to talk to anyone, working in the government, in Ottawa, who is at his office at 8 p.m.

7.4 Conclusion

This chapter showed that several key drivers of innovation loaded on the four constructs (performance, market environment, geologic resources, and environment preservation) based on principal component analysis. Regression analysis was carried out on these constructs as well as collaboration and the role of government to examine the impact of innovation. The results show that the equation consisting of the six construct variables – performance, market environment, geologic resources, the environment preservation, collaboration, and government as independent variables with innovation as the dependent variable provided a reasonably good fit. However, with the exception of the environment variable, the

coefficients of all other variables were statistically insignificant. The results could suggest that the environment or concern for government environmental regulation could be important in forecasting industry's innovation future behavior. To the extent that this is true, government policies that are directed toward innovation to reduce environmental impact could be worthwhile and effective. Industry experts were forthcoming with comments. Some of the issues and concerns raised especially with regards to energy and water use for oil sands development, skill shortages, and the call for super depletion allowances for CO₂ sequestration require further examination.

**Figure 7A. 1: Performance Construct:
Histogram**

**Figure 7A.2: Market Environment
Construct: Histogram**

Figure 7A.3: Geological Resources Histogram

Figure 7A.4: Environment Preservation Construct Histogram

Figure 7A.5: Collaboration Construct: Histogram

Figure 7A.6: Government Support: Histogram

Table 7A.1**Specific Technologies and Performance Variables – Phase of Operation**

	Exploration	Development	Production
Three-dimensional seismology (3D/4D and other advanced seismic technologies)	Reduce unit exploration costs; reduce unit replacement costs; increase productive capacity (e.g., finding new reserves); increase productivity; improve targeting of oil and gas reserve deposits; and improve success ratios.	Reduce unit development costs; reduce unit replacement costs; increase productive capacity (e.g., developing new reserves); increase productivity; improve targeting of oil and gas reserve deposits; and improve success ratios.	Reduce unit supply cost; increase productive capacity (e.g., developing new reserves); increase productivity; and improve targeting of oil and gas reserve deposits.
Horizontal wells (directional wells) Multi-bore	Reduce unit replacement costs; increase productive capacity (e.g., finding new reserves and accessing new reserves); increase productivity; improve targeting of oil and gas reserve deposits; improve success ratios; and increase recovery factors.	Reduce unit development costs; reduce unit replacement costs; increase productive capacity (e.g., developing new reserves); increase productivity; improve targeting of oil and gas reserve deposits; and increase recovery factors.	Reduce unit supply cost; reduce unit operating costs; increase productive capacity; increase productivity; improve targeting of oil and gas reserve deposits; improve producer netbacks; manage production for market conditions (just-in-time); and increase recovery factors.
Advanced field recovery technology (e.g., EOR - water floods, CO₂ injections advanced pumping and production techniques)	—	—	Reduce unit supply cost; reduce unit operating costs; increase productive capacity; increase productivity; improve producer netbacks; and improve market shares.
Oil sands Technology (e.g. SAGD)	—	—	Reduce unit supply cost; reduce unit operating costs; increase productive capacity; increase productivity; improve producer netbacks; and improve market shares.
Transportation and transshipment technology (pipe, valves, pumps, double-hulled tankers)	—	—	Reduce unit transportation costs; reduce environmental impact; and increase productive capacity (improve viability of new projects).
Sustainable development/ environmental technologies (reduced gas flaring, pumps oil spillage reductions, improved valves etc.)	Reduce environmental impact; reduce greenhouse gas emissions; improve community relationships; increase market shares; and better meet environmental regulations / standards.	Reduce environmental impact; reduce greenhouse gas emissions; improve community relationships; increase market shares; and better meet environmental regulations / standards.	Reduce environmental impact; reduce greenhouse gas emissions; improve community relationships; increase market shares; and better meet environmental regulations / standards

Table 7A.2**Performance Variables and Phase of Operation**

	Exploration	Development	Production
Exploration Cost	✓	-	-
Development cost	-	✓	-
Replacement Cost	✓	✓	-
Operating Cost	-	-	✓
Supply Cost	-	-	✓
Productive Capacity	✓	✓	✓
Productivity	✓	✓	✓
Targeting of Oil and Gas Reserves Deposits	✓	✓	✓
Success Ratios	✓	✓	-
Recovery Factors	✓	✓	✓
Management of Production	-	-	✓
Environmental Impacts	✓	✓	✓
Meeting Environmental Regulations / Standards	✓	✓	✓
Greenhouse Gas Emissions	✓	✓	✓
Producer Netbacks	-	-	✓
Community Relations	✓	✓	✓
Market Shares	✓	✓	✓

Table 7A.3

**Equations for Estimation on the Impact of Technology in
Each Phase of Operation (Exploration, Development and Production)**

Variable Nos.	Dependent Variables - Performance	Phase of Operation
1	SEIEXPL - Average performance variable with respect to 3D-4D seismic	Exploration
2	HOREXPL - Average performance variable with respect to horizontal wells	Exploration
3	SUSDIMP - Average performance variable with respect sustainable development technologies	Exploration
4	SEIDEVIM - Average performance variable with respect to 3D-4D seismic	Development
5	HORIDEV - Average performance variable with respect to Horizontal wells	Development
6	SUSTIM - Average performance variable with respect to sustainable development technologies	Development
7	SEISPROD - Average performance variable with respect to 3D-4D seismic	Production
8	HORIZIMP – Average performance variable with respect to horizontal wells	Production
9	AdvfieldREC - Average performance variable with respect to advanced field recovery technology	Production
10	SADGDIM - Average performance variable with respect to oil sands technology	Production
11	TRANS - Average performance variable with respect to transportation and transshipment technology	Production
12	SSD - Average performance variable with respect to sustainable development technologies	Production

Notes: Column 2 shows the variable names of the average performance variables for each technology in each phase of operation.

Figure 7A. 7: Exploration - Impact of 3D/4D and Other Advanced Seismic Technologies on Performance

Figure 7A. 8: Exploration - Impact of Horizontal Wells Technology on Performance

Figure 7A. 9: Exploration - Impact of Sustainable Technologies on Performance

Figure 7A. 10: Development - Impact of 3D/4D and Advanced Seismic Technologies on Performance

Figure 7A. 11: Development - Impact of Horizontal Wells Technology on Performance

Figure 7A. 12: Development - Impact of Sustainable Development Technologies on Performance

Figure 7 A. 13: Production - Impact of 3D/4D and Advanced Seismic Technologies on Performance

Figure 7A. 14: Production - Impact of Horizontal Wells Technologies on Performance

Figure 7A. 15: Production - Impact of Advanced Field Recovery Technologies on Performance

Figure 7A. 16: Production - Impact of Advanced Oil Sands Technology Production on Performance

Figure 7A. 17: Production - Impact of Transportation and Transshipment Technologies on Performance

Figure 7A. 18: Production - Impact of Sustainable Development and Environmental Technologies on Performance

Table 7A.4

One Sample T-Test of Performance Indicators Based on Firm Size

One Sample T Test of Performance Indicators Based on Firm Size								
	Size		Test Value = 0					
		Performance Variables	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
							Lower	Upper
E X P L O R A T I O N	Large	SEIEXPL	16.239	19	.000	3.68333	3.2086	4.1581
		HOREXPL	19.057	19	.000	3.20833	2.8560	3.5607
		SUSDIMP	15.848	19	.000	3.13000	2.7166	3.5434
	Medium	SEIEXPL	13.953	12	.000	3.71795	3.1374	4.2985
		HOREXPL	7.045	12	.000	2.33333	1.6117	3.0549
		SUSDIMP	9.824	12	.000	2.63077	2.0473	3.2143
	Small	SEIEXPL	10.492	23	.000	3.20139	2.5702	3.8326
		HOREXPL	13.688	23	.000	3.00694	2.5525	3.4614
		SUSDIMP	13.245	23	.000	2.42500	2.0462	2.8038
57 Firms								
D E V E L O P M E N T	Large	SEIDEVIM	16.035	22	.000	3.53623	3.0789	3.9936
		HORIDEV	25.836	22	.000	3.76812	3.4656	4.0706
		SUSTIM	20.375	22	.000	3.27826	2.9446	3.6119
	Medium	SEIDEVIM	12.518	15	.000	3.58333	2.9732	4.1935
		HORIDEV	9.079	15	.000	3.13542	2.3993	3.8715
		SUSTIM	11.651	15	.000	2.85000	2.3286	3.3714
	Small	SEIDEVIM	11.966	24	.000	3.34000	2.7639	3.9161
		HORIDEV	12.931	24	.000	2.94000	2.5604	3.5329
		SUSTIM	13.086	24	.000	2.38400	2.0080	2.7600
64 Firms								
P R O D U C T I O N	Large	SEISPROD	10.634	23	.000	2.88330	2.2905	3.3970
		HORIZIMP	18.182	23	.000	3.27083	2.8987	3.6430
		AdvfieldREC	15.271	23	.000	2.87500	2.5816	3.3906
		SADGDIM (*)	10.121	16	.000	3.19608	2.5266	3.8655
		TRANS	10.626	23	.000	2.55556	2.0581	3.0531
		SSD	14.887	23	.000	3.13333	2.6979	3.5687
	Medium	SEISPROD	7.741	15	.000	2.83750	2.0154	3.5471
		HORIZIMP	8.461	15	.000	3.05469	2.2852	3.8242
		AdvfieldREC	12.440	15	.000	2.93750	2.4342	3.4408
		SADGDIM (*)	10.121	16	.000	3.19608	2.5266	3.8655
		TRANS	8.738	15	.000	2.12500	1.6066	2.6434
		SSD	12.246	15	.000	2.85000	2.3539	3.3461
	Small	SEISPROD	8.926	22	.000	2.44350	1.8274	2.9335
		HORIZIMP	12.009	22	.000	2.69565	2.2301	3.1612
		AdvfieldREC	9.737	22	.000	2.16667	1.7052	2.6282
		SADGDIM (*)	10.121	16	.000	3.19608	2.5266	3.8655
		TRANS	10.278	22	.000	2.01449	1.6080	2.4210
		SSD	14.090	22	.000	2.32174	1.9800	2.6635
63 Firms								

Note: (*) Given the small number of companies involved in oil sands operations, statistics were computed for the group as a whole.

Table 7 A.5

**Exploration: Regression Coefficients – Impact of 3D/4D
and other Advanced Seismic Technologies on Performance ^(a)**

R ² = .893	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
EQ: 1 (Constant)	.133	.142		.939	.351
Use of 3D-4D seismic in exploration activities	.847	.036	.945	23.306	.000

(a) Dependent Variable: SEIEXPL

Table 7 A.6

**Exploration: Regression Coefficients – Impact
of Horizontal Wells Technology on Performance**

R ² = .64	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
EQ: 2 (Constant)	.632	.206		3.068	.003
Use of Horizontal (directional) multi-bore wells in exploration activities	.672	.062	.800	10.747	.000

(a) Dependent Variable: HOREXPL

Table 7A.7

**Exploration: Regression Coefficients – Impact of
Sustainable Development and Environmental Technologies on Performance**

R ² = .684	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
EQ: 3 (Constant)	.539	.180		2.994	.004
Use of sustainable development environmental technologies in exploration activities	.678	.057	.827	11.860	.000

(a) Dependent Variable: SUSDIMP

Table 7 A.8

**Development: Regression Coefficients – Impact of
3D/4D and other Seismic Technologies on Performance**

$R^2 = .776$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 4	B	Std. Error	Beta		
(Constant)	.315	.215		1.465	.148
Use of 3D-4D and other advanced seismic technologies in development activities	.817	.054	.881	15.122	.000

(a) Dependent Variable: SEIDEVIM

Table 7 A.9

**Development: Regression Coefficients – Impact
of Horizontal Wells Technology on Performance**

$R^2 = .467$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 5	B	Std. Error	Beta		
(Constant)	1.244	.301		4.133	.000
Use of Horizontal directional multi-bore wells in development activities	.593	.080	.684	7.376	.000

(a) Dependent Variable: HORIDEV

Table 7 A.10

**Development: Regression Coefficients – Impact
of Sustainable Development and Environmental Technologies**

$R^2 = .415$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 6	B	Std. Error	Beta		
(Constant)	.972	.279		3.485	.001
Use of Sustainable development & environmental technologies in development activities	.567	.083	.644	6.836	.000

(a) Dependent Variable: SUSTIM

Table 7 A.11

**Production: Regression Coefficients –
Impact of 3D/4D Seismic Technology on Performance**

$R^2 = .469$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ:7	B	Std. Error	Beta		
(Constant)	1.027	.254		4.044	.000
Use of 3D-4D seismic in production activities	.584	.080	.685	7.346	.000

(a) Dependent Variable: SEISPROD

Table 7 A.12

**Production: Regression Coefficients –
Impact of Horizontal Wells Technology on Performance**

$R^2 = .589$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 8	B	Std. Error	Beta		
(Constant)	.816	.230		3.543	.001
Use of Horizontal wells in production activities	.674	.069	.767	9.722	.000

(a) Dependent Variable: HORIZIMP

Table 7 A .13

**Production: Regression Coefficients –
Impact of Advanced Field Recovery Technology on Performance**

$R^2 = .416$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 9	B	Std. Error	Beta		
(Constant)	.773	.306		2.526	.014
Use of advanced field recovery technology in production activities in production activities	.584	.089	.645	6.589	.000

(a) Dependent Variable: AdvfieldREC

Table 7 A.14**Production: Regression Coefficients – Impact
of Oil Sands Recovery Techniques on Performance**

$R^2 = .381$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 10	B	Std. Error	Beta		
(Constant)	.580	.899		.645	.529
Use of oil sands recovery processes in production activities (e.g., SAGD)	.618	.203	.617	3.037	.008

(a) Dependent Variable: SADGDIM

Table 7 A.15**Production: Regression Coefficients
Impact of Transportation and Transshipment Technologies on Performance**

$R^2 = .378$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 11	B	Std. Error	Beta		
(Constant)	.872	.238		3.670	.000
Use of transportation and transshipment technologies in production activities	.653	.103	.615	6.336	.000

a Dependent Variable: TRANS

Table 7 A.16**Production: Regression Coefficients – Impact of
Sustainable Development and Environmental Technologies on Performance**

$R^2 = .465$	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
EQ: 12	B	Std. Error	Beta		
(Constant)	1.003	.241		4.157	.000
Use of sustainable development and environmental technologies in production activities	.576	.076	.682	7.581	.000

(a) Dependent Variable: SSD

CHAPTER 8

COLLABORATION IN THE UPSTREAM OIL AND GAS SECTOR

This chapter will provide analysis on collaborative agreements in the upstream oil and gas sector by discussing the institutions with which firms collaborated and the reasons for collaboration. Comments received from both industry experts and the government are also discussed in this chapter.

8.1 Overview

The literature review, earlier in this thesis, points to several reasons why firms may want to engage in collaboration: to lower costs, share risks, access skills, and pursue R&D. Key participants in collaboration include universities, government, competitors, research institutes, and foreign companies. The NPC (1995) notes that collaboration will become increasingly important in the future in the petroleum sector. There are many reasons for collaborative research; these include reducing cost, sharing risks, gaining expertise, internalizing economic externalities, and co-ordinating strategies, as discussed in Chapter 2.

Since the mid-1990s, two non-traditional organizations have emerged. Canadian Oil Sands Network for Research and Development (CONRAD), and the Petroleum Technology Alliance Canada (PTAC). CONRAD is focussed on non-conventional oil activity (i.e., oil sands) and PTAC is focussed on collaboration to develop innovations in the upstream oil and

gas industry. NRCan (CANMET's Western Research Centre) collaborates with both these organizations and an NRCan official sits on the executive Committee of PTAC. Syncrude and Suncor collaborate with each other and with companies, governments, universities, and research centres. They are industry leaders and are involved in research areas that cover the value chain of oil sands operations, including extraction, upgrading, and reusing material.

8.2 Cooperative Agreements with Other Organizations

As noted earlier, 65 percent of the total respondents indicated that they were involved in cooperative agreements with other institutions (participation in joint projects in developing advanced technologies and processes for use in upstream activities). The companies that were involved in cooperative agreements were asked about the extent of cooperation (where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive) with the following institutions:

- Universities and colleges;
- Federal laboratories (e.g., NRCan at Devon labs);
- Research Institutes (e.g., National Research Council);
- Provincial & territorial governments;
- Suppliers of equipment and materials;
- Competitors; and
- Foreign companies;

The results show that:

- 34 percent firms rated their collaboration with universities and colleges as ranging from reasonable to extensive;
- 18 percent of firms rated their collaboration with federal laboratories (e.g., NRCan at Devon labs) to range from reasonably to extensive;
- 23 percent of firms rated their collaboration with Research Institutes (e.g., the National Research Council) to range from reasonably to extensive;
- 27 percent rated their collaboration with provincial & territorial governments to range from reasonably to extensive;
- 75 percent rated their collaboration with suppliers of equipment and materials to range from reasonably to extensive;
- 59 percent rated their collaboration with competitors to range from reasonably to extensive; and
- 13.6 percent rated their collaboration with foreign companies to range from reasonably to extensive.

Table 8.1 shows the mean values of the extent of cooperation with these institutions. Agreements with competitors were ranked highest followed by suppliers of equipment and materials. Cooperative agreements with foreign companies ranked the lowest. As well, cooperation with the federal government labs and provincial labs do not rank high.

Table 8.1

Mean Values of Cooperative Agreements with Other Organizations

	Mean	Std. Deviation
Universities and colleges	2.11	1.039
Laboratories – (e.g., NRCan at Devon labs)	1.61	.920
Research Institutes (e.g., National Research Council)	1.77	.961
Provincial and territorial governments	1.89	1.017
Competitors	3.20	1.133
Suppliers of equipment and materials	2.84	1.256
Foreign companies	1.55	.848

8.3 Reasons for Cooperation

Firms were asked of the extent to which the following factors were important on a five point scale from 1 to 5 (not at all important, somewhat important, reasonably, substantial, and extensive) in determining the level of involvement in collaboration of their firm:

- Sharing costs;
- Sharing risks;
- Sharing facilities;
- Accessing new knowledge;
- Accessing R&D; and
- Developing new markets.

Provided below are the firms' ratings of these factors:

- 75 percent of firms ranked sharing costs as being important to extremely important;
- 77.3 percent noted sharing risks as being important to extremely important;
- 47.7 percent saw sharing facilities as being important to extremely important;
- 86.4 percent saw the access of new knowledge as being important to extremely important;
- 72.7 percent ranked accessing R&D as important to extremely important; and
- 11.3 percent indicated developing new markets was important to extremely important.

The results demonstrate that accessing new knowledge, sharing costs, sharing risks and accessing R&D are important to oil and gas companies. Sharing facilities and cooperating to develop new markets are less important to firms in this industry.

Table 8.2 shows the mean values and the standard deviations of the reasons for cooperation. Accessing new knowledge, accessing R&D, and sharing risks ranked the highest among the six factors.

Table 8.2

Mean Values on Reasons for Cooperation

	Mean	Std. Deviation
Sharing costs	3.09	1.007
Sharing risks	3.34	1.180
Sharing facilities	2.48	1.229
Accessing new knowledge	3.68	.983
Accessing R&D	3.36	1.348
Developing new markets	1.52	.876

The mean values were also estimated for the group size of firms: small, medium, and large and integrated firms. Overall, large firms exceeded medium-sized and small firms in all categories except with respect to the importance of developing new markets where

medium-sized firms exceeded large and integrated firms. Looking at individual groups, accessing new knowledge and R&D ranked the highest for large and integrated firms as well as medium sized firms. Sharing risks and sharing costs ranked the highest for small companies.

The Cronbach Alpha for these variables was estimated at .357, suggesting that the reasons for cooperation as a group are not highly related. When these variables were then checked for inter-correlations it was found that:

- sharing costs and sharing risks were reasonably correlated with a Pearson correlation coefficient of .736 they were significant at the .01 level; and
- accessing new knowledge and R&D were also reasonably correlated with a Pearson correlation coefficient of .774 they were significant at the .01 level.

8.4 Comments Received from Industry

The comments received on collaboration from industry experts are summarized below.

- CONRAD focuses on pre-competitive research with respect to oil sands development and they will meet to discuss problems and how to address them.
- PTAC is somewhat like CONRAD but focuses more on conventional oil and recently heavy oil.
- PTAC has been successful in bringing companies to put money on the table to address particular industry problems.

- There is a general acceptance of collaborating when there is an urgency to develop new technologies (including environmental technologies).
- Ten organizations studied more than 500 technologies to collaborate and only one or probably two technologies were thought to be useful. They seemed to favor only a few firms and, finally, the whole idea of pursuing developing any of these was dropped completely.
- The industry needs to be quick to market – needs to get the technology through the door and quickly into the field without spending time and money to develop it.
- The Hibernia project benefited from successful transfer of technologies from the North Sea.
- The industry is prepared to go around the world and pay whatever it takes to get the technology.
- The industry is interested in getting the oil quickly from the ground and is risk averse in trying unproven technologies.
- Water is considered a big problem in industry but no one is collaborating to find solutions.
- Carbon capture and storage – this is a big issue and significant scope exists for collaboration.

8.5 Comments Received from Government

- Government's agenda is broader. Government research and investment are focused in all areas – conventional areas, offshore, oil sands, and the North, environment, and clean air.
- Partnerships are an important part of NRCan programs.²⁹ The collaboration that takes place with other Federal Departments, industry associations, the provinces, municipalities, universities, and other funding programs is important.
- Government collaboration with industry is focused on pre-competitive technologies and with a longer term focus on air quality, the environment, including emissions, oceanography, and safety. Also important is R&D and innovation in transportation, pipelines, iceberg bits (small icebergs that could impact on production platforms), and long term energy security that includes renewable energy, energy efficiency, and getting oil that's left in the ground.
- Government and industry collaboration takes place at the project level, for example, dealing with tailing ponds at the major oil sands plants.
- The CO₂ capture and storage project is a prime example of government, industry and experts from other areas collaborating. CO₂ capture and storage have huge potential benefits from an enhanced oil recovery perspective and from an environmental standpoint for reducing greenhouse gas emissions and addressing global warming.

²⁹ NRCan scientists, engineers and technical officers were interviewed.

- Government, industry and university collaboration takes place but only among variations of two of the three, not among the whole group. Collaboration among the three groups needs to take place.
- Collaborating could result in a competitor organization hiring employees away from government labs; this is not necessarily bad but it takes a long time to hire a replacement, given the staffing process, to replace personnel in government.

8.6 Conclusion

This chapter examined collaboration on innovation in the upstream petroleum industry. It was found that firms collaborated to a great extent with their competitors and suppliers of equipment and materials. The most important reasons for collaboration are to access new knowledge and R&D. Industry collaborates through consortia where there is an urgency to deal with a problem. Industry, however, is interested in getting technology quickly into the field and is not interested in waiting too long for development. It is, thus, willing to buy the technology off the shelf to quickly get it into the field. The view from government is that collaboration is focused on long term public policy goals such as the environment, energy security, and a balanced approach to developing oil and gas resources in conventional areas, the Northern frontiers, and offshore regions. The CO₂ capture and storage project which involves government (NRCan), the Alberta government, industry partners and international experts is a prime example of a project geared to long-term policy goals of reducing greenhouse gas emissions and the consequent impact on global warming. It also has potential impact of improving oil supply through enhanced recovery.

CHAPTER 9

GOVERNMENT SUPPORT

This chapter examines government support within the upstream oil and gas sector with respect to innovation.

9.1 Overview

As noted earlier, the government sees innovation as being quite important from the standpoint of improving productivity and standards of living, and it has made significant commitments to innovation. In the past, the government played an active role in many aspects of the industry in terms of pricing, revenue sharing, and taxation. The National Energy Program (NEP) of 1980 was a major policy instrument by the Government of Canada with respect to these issues. The federal government has also provided significant assistance to enable mega projects – such as Hibernia, Terra Nova, and the Lloydminster Upgrader – to proceed, and accelerated capital cost allowance for oil sands and in-situ projects. Today, the upstream oil and gas industry operates in a “market oriented” environment. The natural resources sector is a case in point. Government involvement in terms of regulation, fiscal frameworks, and financial assistance can be instrumental in driving innovation, as discussed in earlier.

Government is still involved in the industry through taxes, royalties, various forms of regulations (including environmental regulations), incentives, research labs, and partnerships;

these government bodies include NRCan, Environment Canada, NRCan's lab in Devon, Alberta, the National Research Council, and the Alberta Research Council. More generally, Canada's *Innovation Strategy*, launched in 2002, committed the government to providing significant funding for R&D. Government has made several policy statements to suggest that industry's reliance on advanced technologies would reduce the impact of climate change. Government makes significant outlays of capital investment for innovation and it has a large number of programs and policies influencing innovation.

As noted in Chapter 2, SR&ED is one such program and it is considered the largest in Canada for influencing innovation. The program is also considered to be one of the most generous federal R&D tax incentive programs in the world and the provinces also provide generous treatments. Other than Prince Edward Island, Alberta is the only province that does not provide R&D tax credits similar to that of the SR&ED. The 2007 federal Budget also calls for identifying opportunities to improve the R&D incentive program. The commitments by governments to innovation are also discussed in greater detail in Appendix 3. An issue that was raised frequently is whether there is sufficient information in the public domain to understand whether industry sectors are making use of the program or not. Of great interest is the effectiveness of the SR&ED incentive program particularly as it relates to the natural resources sector (Centre for the Study of Living Standards (CSLS), 2005). One recent impetus for a fresh look at the program has come from the federal S&T Strategy including its administration to further encourage R&D within the business sector (Industry Canada, 2007).

9.2 Importance of Government Programs and Policies

Companies were asked to rate on a Likert type scale of one to five, the importance of government programs where 1 = not at all important, 2 = somewhat important, 3 = important; 4 = important; and 5 = extremely important. The frequency tables provided at the end of Chapter 9 show the importance of government involvement through programs and policies with respect to innovation in the following six areas:

- R&D tax credits (e.g., SR&ED);
- Government technology and support program;
- Employee exchange program;
- Government fiscal framework (re-exploration, development, production);
- Partnerships with government labs; and
- Government support for training.

The frequency tables show that a high number of responses ranked the importance of government programs to their innovation activity as extremely low except for fiscal policy, including SR&ED. Two companies did not answer this question on government support programs and policies. The following shows how firms rated government policies and programs from important to extremely important:

- R&D tax credits (e.g., SR&ED) – 36.4 percent;
- Technology and Support Programs – 22.7 percent;
- Employee Exchange Program – 12.1 percent;
- Fiscal framework on exploration, development, and production – 32 percent;

- Partnerships with government labs – 10.6 percent; and
- Support for training – 12.1 percent.

No firm ranked partnerships with government labs beyond being important. Only one company placed the employee exchange program variable as being extremely important. Overall, what is noticeable is that a large percentage of firms rank these government programs and policies as not at all important or only somewhat important.

Table 9.1 shows the mean values of the importance of government programs. The results show that the government fiscal framework and R&D tax credits rank as the highest followed by government technology support programs. Notwithstanding, the mean values are not very high and rank between somewhat important and important.

Table 9.1

Importance of Government Support and Innovation

	Mean	Std. Deviation
R&D tax credits	2.24	1.458
Government technology and support program	1.80	1.056
Employee exchange program	1.39	.742
Government fiscal framework (re-exploration, development, production)	2.88	1.544
Partnerships with government labs	1.50	.685
Government support for training	1.56	.879

The Pearson correlation coefficient of internal R&D and R&D tax credits, estimated at .429, and is shown in Table 9.2.

Table 9.2

Internal R&D and Government R&D Tax Credits

		Internal research and development (R&D)	R&D tax credits
Internal research and development (R&D)	Pearson Correlation	1	.429(*)
	Sig. (2-tailed)		.000
R&D tax credits	Pearson Correlation	.429(*)	1

* significant at the .01 level

Table 9.3

**Correlation of Government Fiscal Framework
(Re-exploration, development, production) and Innovation**

		Government fiscal framework (re-exploration, development, production)	
Government fiscal framework (re-exploration, development, production)	Pearson Correlation	1	.304(*)
INNOVF	Pearson Correlation	.304(*)	1

* Correlation is significant at the 0.05 level (2-tailed).

Government fiscal programs are correlated with innovation, albeit somewhat moderately.

Earlier in Chapter 7, a construct consisting of the average of all the variables above was regressed against the innovation (which consisted of three variables). It was shown that government programs and policies have an impact on innovation. When the construct was

included in a multiple regression equation with several relevant constructs, it was found that the variable for government assistance was insignificant; in part this was due to multicollinearity with other variables.

9.3 Firm Size and Government Policies and Program

Analysis was carried out to determine whether firm size made a difference. The mean values for each program by the three firm sizes – small, medium and large and integrated – were estimated. The detailed data are presented in Table 9A.7 in the Appendix.

- The results show that: government fiscal framework followed by R&D tax credits are most important to firms in all three groups; and
- The mean values of R&D tax credits and government fiscal policies are significantly higher for large firms than for medium and small firms.

9.4 Comments Received from Industry

Comments received on government programs are provided below.

- The rate of the SR&ED program is good but understanding the program is complex and requires an investment of time.
- SR&ED could be extended to cover demonstration / development projects.

- If it works, firms will use research done by governments but if it is not cost effective they will not use it. There is a level of “arrogance” that the company’s technology is best.
- Companies prefer dealing with their own community and their head offices.
- A high level of emphasis is placed on confidentiality. Secrets are safely guarded and trust must not be broken.
- Employee exchange with government is focused more in gaining understanding of regulations. Such exchange involves agreements on secrecy, intellectual property rights, patenting, and concerns about liability.
- Innovation in the sector is a result of competition and very little government interference.
- More innovation has occurred where government has directly seeded research as Alberta Oil Sands Technology Research Authority (AOSTRA) – Underground Test Facility (UTF) or revised fiscal regimes (e.g., horizontal well royalty in Saskatchewan, Alberta oil sands royalty). The UTF was part of the development of the SAGD.
- Government regulation needs to be simplified; the use of a single window approach is needed.
- There is need for government funding/super-depletion for a CO₂ pipeline to conserve/sequester CO₂ in Fort McMurray; there is also the possible use of super-depletion in other R&D areas.

9.5 Conclusion

This chapter examined the impact of a number of government programs on innovation. It was found that the government fiscal policy on exploration, development, and production, followed by R&D tax credits are the most important programs. This is true for firms of all sizes but these two government instruments have greater impacts on large and integrated firms. The results show that there is some level of correlation between R&D incentives and R&D undertaken by firms. The results also show that correlation exists with fiscal policy and the acquisition of advanced machinery and equipment, advanced processes, and other external knowledge. A key comment received with respect to SR&ED is that the program could be expanded to cover development activities. An interesting point also made is the use of super depletion allowance in the area of sequestering CO₂. The next chapter will discuss the results of the analysis presented in chapters 6 to 9.

Table 9 A.1

R&D Tax Credits – Frequency of Use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	32	47.1	48.5	48.5
	2	10	14.7	15.2	63.6
	3	7	10.3	10.6	74.2
	4	10	14.7	15.2	89.4
	5	7	10.3	10.6	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9 A.2

**Government Technology and
Support Program – Frequency of Use**

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	35	51.5	53.0	53.0
	2	16	23.5	24.2	77.3
	3	10	14.7	15.2	92.4
	4	3	4.4	4.5	97.0
	5	2	2.9	3.0	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9 A.3

Employee Exchange Program – Frequency of Use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	49	72.1	74.2	74.2
	2	9	13.2	13.6	87.9
	3	7	10.3	10.6	98.5
	4	1	1.5	1.5	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9 A.4

Government Fiscal Framework – Frequency of Use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	21	30.9	31.8	31.8
	2	6	8.8	9.1	40.9
	3	12	17.6	18.2	59.1
	4	14	20.6	21.2	80.3
	5	13	19.1	19.7	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9 A.5

Partnerships with Governments Labs – Frequency of Use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	40	58.8	60.6	60.6
	2	19	27.9	28.8	89.4
	3	7	10.3	10.6	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9A.6

Government Support for Training – Frequency of Use

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	41	60.3	62.1	62.1
	2	17	25.0	25.8	87.9
	3	5	7.4	7.6	95.5
	4	2	2.9	3.0	98.5
	5	1	1.5	1.5	100.0
	Total	66	97.1	100.0	
Missing	999	2	2.9		
Total		68	100.0		

Table 9 A.7**One-sample Statistics Based on Group Size**

	N	Mean	Std. Deviation	Std. Error Mean
Large & Integrated Companies				
R&D tax credits	25	3.08	1.382	.276
Government technology and support program	25	2.28	1.100	.220
Employee exchange program	25	1.56	.821	.164
Government fiscal framework (re-exploration, development, production)	25	3.36	1.350	.270
Partnerships with government labs	25	1.88	.726	.145
Government support for training	25	2.08	1.115	.223
Medium - Sized Companies				
R&D tax credits	17	1.88	1.453	.352
Government technology and support program	17	1.71	1.105	.268
Employee exchange program	17	1.47	.874	.212
Government fiscal framework (re-exploration, development, production)	17	2.29	1.490	.361
Partnerships with government labs	17	1.35	.606	.147
Government support for training	17	1.35	.606	.147
Small Sized Companies				
R&D tax credits	24	1.63	1.135	.232
Government technology and support program	24	1.38	.770	.157
Employee exchange program	24	1.17	.482	.098
Government fiscal framework (re-exploration, development, production)	24	2.79	1.668	.340
Partnerships with government labs	24	1.21	.509	.104
Government support for training	24	1.17	.381	.078

CHAPTER 10

DISCUSSION AND IMPLICATIONS OF THE RESULTS

This chapter will discuss the analyses undertaken in chapters 6 to 9 about the survey results. Chapters 6 and 7 provided descriptive and regression analyses of the survey responses. Chapter 8 and Chapter 9 provided an in-depth analysis of collaboration and of the participation of government in this sector.

10.1 Sample

A total of 68 firms responded to the survey. From a statistical standpoint, the sample used in this study, in absolute terms, is small. It should be noted, however, that the number of firms that are operators in exploration, development, and production is a small number. Additionally, the survey captured a significant share of industry operators — more than 40 percent. This number rises to 50 percent when adjustments are made for extremely small firms in the industry who could not fill out the survey. Significant efforts were made to obtain responses from the industry. Several companies indicated that they were too small to fill out the survey questionnaire. Industry associations such as the Canadian Petroleum Association, the Energy Council of Canada, and the Heavy Oil Association of Canada supported the survey.

Initially, the expectation was to receive responses from about 50 companies who account for 30 percent of industry production. The Canadian Association of Petroleum Producers had

indicated that if responses from about 30 firms could be obtained, it should be possible to get sufficient information for an accurate analysis. With significant efforts and support this number was exceeded. In this concentrated sector, the number of firms that responded to the survey accounts for about 80 percent of the industry revenues, production, and industry projects. As well, many companies have joint project arrangements and farm-in agreements with other companies in the industry. Almost all firms in the industry with revenues above \$1B and/or with employees above 1000 responded to the survey. Further, the sample captures the firms who also account for most of Canada's oil sands production, a rapidly growing source of supply of crude oil in Canada. Similarly, the survey captured a high percentage of firms involved in CBM. CBM is expected to play an important role in Canada's future natural gas supply. It is unlikely, therefore, that the results of this study would change significantly even if the sample were larger.

10.2 Drivers and Impact of Innovation

Reducing development, replacement, and operating replacement costs were found to be strong drivers in this industry. Increasing productive capacity ranked as the highest driver, followed by operating costs, and productivity. It could be argued that when prices are high in the world markets firms can go after higher cost resources without investing significantly in innovation. Over the past three years, oil and natural gas prices have been fairly robust. It is recognized in the industry that firms use a high discount rate and seek quick payout of projects. Firms develop their own view of prices to carry out their analyses. This, in a way, provides some isolation from rapid swings in the marketplace. As well, the industry typically

uses internal cash flow and is not highly dependent on capital markets for exploration and development activity. The future outlook calls for robust long-term average prices and a bright outlook for energy demand from the U.S. for Canadian oil and natural gas supplies. Most of Canada's oil and natural gas are exported to the U.S. Growing demand from countries such as China and India is likely to provide additional pressure on demand. Hence, it is not surprising that firms see productive capacity, operating costs, and productivity as the main drivers.

Environmental regulations are important in driving the use of technologies. The results suggest that firms are using technology to address environmental and sustainable development concerns and environmental regulations. Porter (1998a) argues that the current system of environmental regulation in the U.S. often deters innovative solutions or renders them impossible due to the sheer inefficiencies with which regulations are administered. He also notes that the current system of environmental regulation in the U.S. often deters innovative solutions or renders them impossible because of the strictness in the way standards are written and the sheer inefficiencies in the way regulations are administered. In this study, the environment was found to be an important driver of innovation. More particularly, it was found that environmental regulation and reducing environmental impacts were important drivers of innovation, but less important for reducing greenhouse gas emissions. It appears that managers of the upstream sector accept that environmental regulation is a business requirement as well as a social responsibility. This finding suggests that providing the right mix of regulation and leaving firms to undertake innovation may result in favorable impacts. Stavins *et al.*, (2003, p. 2) of the John F. Kennedy School of

Government, Harvard University note that: “in the 1990s – environmental targets were made more stringent and environmental quality improved.” This may also suggest that regulation with regards to greenhouse gas emissions may be an effective tool in reducing greenhouse gas emissions through innovation. A typical view from industry, however, is that regulations are multi-layered and burdensome and that a single window approach to regulation would be more efficient.

10.3 Application of Technology

The application of technology was shown to have a strong impact on performance, which suggests that without the investment in advanced technologies oil and gas supplies would have been significantly lower. It also suggests that Canada’s future oil and natural gas supplies could increase due to the use of advanced technologies. This study contributes to the view that resources should not be treated as a fixed stock but as a flow that can be improved. This could have implications for the way analysts forecast oil supply. Also important is the increase in the number of major projects. In the past, the search for conventional oil and supplies dominated a firm’s investment decision. This raises an interesting issue for researchers and energy modelers who have previously focused most of their attention on exploration analysis in conventional areas. Fisher (1964), a well-known research exploration modeling expert who used an econometric approach to project oil and production, has dominated the field in this area. Persaud and Kumar (2001) highlight the key approaches to forecasting oil and gas supply (e.g., econometric, extrapolation, geologic, and cash flow models) and present an eclectic approach to forecasting oil and gas supply.

The analyses of this thesis found that a high percentage of oil and gas firms relied heavily on several advanced technologies including – 3D and 4D seismic, horizontal wells, and SAGD – thus demonstrating the importance of advanced technology to this sector. A large number of firms relied upon the technologies in the various phases of operation in the oil and gas sector. This is in sharp contrast to the manufacturing sector, where Baldwin and Sabourin (1995), found that only about one third of Canadian firms used advanced technology in their production processes in 1993. The finding suggests that firms in the upstream oil and natural gas sector are highly innovative. The findings of this study may help to dispel the myth that the natural resources sector which has a relatively low R&D to GDP ratio is not a “low tech” or a sunset industry. Similarly, a country with a low R&D to GDP ratio may not necessarily be less innovative than a country with a high one. A country may import a significant amount of its advanced technology and also benefit from technological spillovers, as Canada does.

It is worthwhile noting, that in periods of high exchange rates, as Canada is experiencing at present, imports of machinery and equipment becomes cheaper and this also give a boost to innovation. In addition, natural resources are experiencing relatively high prices over the past several years and are contributing to high exchange rate of the Canadian dollar.

10.4 Research and Development

The analysis of the survey results demonstrate that internal R&D as a source of innovation activity ranks fairly low in the oil and gas sector but acquisition of external knowledge is

important. This does not mean that R&D is unimportant to the sector or to innovation; rather it suggests that firms, by acquiring advanced machinery and equipment, are purchasing imbedded R&D. In fact, the firms in the sector consider themselves highly innovative. Because the time needed to develop technologies is fairly long, firms which need technologies immediately are driven to buy them off the shelf. Firms may not be able to wait for several years until technologies have been developed. One company representative noted that “even the folks in the white lab coats” realize that companies cannot wait too long to develop technologies; when industry needs technologies it needs them now. In essence, it could be argued that operators in exploration, development, and production drive innovation through their suppliers and through other sectors of the economy that supply innovation and advanced machinery and equipment to the sector.

10.5 Firm Size

The literature suggests that innovation with respect to firm size is mixed. It is interesting to note that small firms do less internal R&D than medium and large and integrated companies, according to the survey results. Large and integrated firms had higher use of the six technologies in exploration, development and production. Large firms tend to be involved in large projects that call for significant capital outlays such as oil sands. Of the 17 companies that indicated that they were involved in oil sands activity, 13 fell into the large and integrated group; oil sands development call for large capital outlays. As well, major companies were the first to be involved in oil sands production. Mazzucato (2000) notes that

innovation, with respect to size, is industry specific and this should be borne in mind in interpreting these results.

The impact of 3D/4D seismic technologies is greater for large versus small firms, and medium versus small firms. The impact of horizontal wells for large and integrated firms exceeds that of medium-sized and small firms in exploration. Both 3D/4D seismic technologies and horizontal wells rely on significant expertise and are expensive. Advanced field recovery techniques also have greater impact on large and integrated firms versus medium-sized and small firms. Ownership of leases, access to some of the older large pools and economies of scale are probably factors may explain the difference in impacts. Large and integrated firms also have a cash flow advantage to medium and small firms.

10.6 Collaboration

Experience has shown that the prospects for promoting and accelerating innovation are optimized when the generation of expertise, knowledge, and technology and the fostering of a business environment are met concurrently through targeted partnerships among governments, business, and academia. Consortia have grown in the resource sector and are likely to play an increasingly important role in the future (Globerman, *et al.*, 1999). The results of the survey undertaken for this thesis demonstrate that while companies are taking advantage of partnerships it is crucial that they have strong links with suppliers and competitors for accessing external knowledge.

Collaboration is considered important to the sector. A high number of the companies that responded to the questionnaire, 65 percent, indicated that they collaborate. Access to external knowledge is the major focus of collaboration. Cost saving as a reason for collaboration did not rate strongly. R&D is not as important for collaboration, which might explain the reasons why companies place less emphasis on cost reduction as a variable influencing their participation in collaboration. Some comments received suggest that firms depend on service companies to provide technologies but that there is cooperation and collaboration that influence the decisions with regards to developing technologies.

From the analysis, collaboration with government does not come across as an important variable. This probably could be explained by the fact that government collaboration is more focussed at the pre-competitive level with firms that are in the petroleum industry but are not operators *per se*. This also includes firms that provide technologies to the industry. Another possibility is that the role government plays with regard to technology development is more focussed on the immediate use of technology and, thus, is not evident to the oil and gas upstream sector. Yet it was recognized that where government was involved in specific technology projects collaboration was important.

R&D was discussed extensively in Chapter 2. It was noted earlier that the resources sector relies on external sources of machinery and equipment. The NPC's (1995) research indicates that only a few companies were doing in-house research, although the outcomes of such programs were vital to their future business interests and/or their long-term viability. Table AP 1.2 in Appendix 1 shows NPC's new paradigm for the industry in the U.S. More than 50

percent of the total oil is produced by organizations having essentially no research, development, and demonstration (RD&D) programs, according to the U.S. NPC. Only about a dozen producers (mainly industry leaders such as Exxon and Shell) out of 1000 support in-house RD&D (NPC, 1995).

Moreover, in-house R&D takes place only where the outcomes of those programs are vital to their future business interests and viability. In addition, most of the RD&D is focussed on the short term, with expectations for products within three years. Service and equipment companies (e.g., Schlumberger) provide most of the technologies to oil and gas companies. The IEA (1997) argues that a new paradigm for oil and gas R&D may also suggest significant opportunities for greater international cooperation among member countries and the oil and natural gas industry. The new paradigm suggests a greater reliance on user-driven collaborative R&D (including government-industry) to compensate for smaller in-house industry R&D programs.

10.7 Government

The government plays an important role in the national innovation system, accepting the importance of free markets and at the same time the need for enhanced partnerships. We can expect the government to continue using its generous tax incentives to spur R&D (CBOC, 2002). The Canadian 2007 Budget has indicated that the government intends to look at the SR&ED program with the opportunity to improve it and its administration. There is debate

on the effectiveness of and possible changes to the program and whether companies are making full use of the program.

The results suggest that the impact of government's policies and programs are relatively low. Of government involvement, fiscal policy was found to be the most important for the oil and gas industry. According the Expert Panel on Commercialization (2005), a culture of innovation must be supported by a tax regime in Canada that is internationally competitive. Mintz, *et al.*, (2005) notes, however, that Canada has the second highest tax rate on capital (taking into account corporate income and other capital related taxes) among 36 developed and developing countries. In the oil and gas sector, the fiscal system in place is considered reasonable based on lower taxation to spur new development.

In February 2007, the Government of Alberta established a panel to assess the royalty regime of the province with respect to oil and gas. One suggestion received was for a super depletion allowance for the sequestration of CO₂ emissions. Such an allowance had resulted in refunds to companies above what they had spent. Expanding the SR&ED may not have the direct impact of innovation in the upstream sector, however but through the suppliers of technology to the sector. The suggestion that came across from industry comments is that fiscal policy on exploration, development, and production are preferable. Government is involved in the industry in the development of pre-competitive technologies and with a longer term focus on the environment, including emissions, oceanography, and safety. The Science and Technology Strategy, recently released by the Prime Minister of Canada shows that energy and natural resources, and the environment are key priorities of this strategy.

CHAPTER 11

CONCLUSION

This thesis investigated innovation in the upstream crude oil and natural gas sector, a strategic part of the Canadian economy and a vital industry for North American energy trade and security. Furthermore, the upstream crude oil and natural gas sector is a major part of Canada's natural resources industry, which plays an important role in the standard of living and well being of Canadians. Significant interest exists in understanding innovation in this sector from both a private and a public policy perspective. Interest in the sector has intensified recently, given concerns about the availability of the world's oil supply, Canada's oil sands development, global warming, and, the potential of Canada becoming an "energy superpower."

Canada's upstream sector is unique in the world in terms of the variety of sources of oil and gas supplies, including conventional light and heavy oil, oil sands, and frontier supplies. Canada's upstream sector and that of the U.S. are similar in that they are both high cost producers and have the most explored basins in the world. Major projects account for an increasingly larger share of Canada's oil supply. The development of these projects is a reflection of the decline in lower-cost conventional oil. The sector faces significant challenges to reduce costs in the face of depleting conventional reserves, to tap higher-cost sources of supply from Canada's frontier (offshore and northern) and oil sands (very heavy oil), and, at the same time, to meet more stringent environmental and sustainable

development constraints. In an increasingly global economy, firms have to be highly innovative to gain and retain a competitive advantage. The application of advanced major technologies in the upstream petroleum sector is relatively recent over the history of the industry. This is partly due to the fact that oil and gas resources were relatively easy to find and develop. Further, there is a paucity of literature on technological innovation in the upstream sector. The use of oil and natural gas is expected to continue to play a crucial role in developed economies and rapidly developing economies such as China and India in this century. Further oil and natural gas use and production have major implications for the environment

The study examined the drivers of innovation by companies involved in exploration, development, and production in the upstream petroleum industry and the impact of their innovation activities, through major technologies, on their performance. The thesis focussed on process innovation, which involves the adoption of a new or significantly improved production technologies and process, as distinct from product innovation, which is based on the development and commercialization of a product with improved characteristics to deliver new services to the consumer.

The thesis has developed an investigative framework to examine the drivers of innovation and the impact of innovation on performance in the upstream petroleum industry, based on a comprehensive review of the literature. The research employed a survey questionnaire that was developed to obtain data and information that is missing from the literature and not publicly available, and to test key relationships of innovation and performance indicators.

There were 68 respondents who completed the survey accounting for over 40 percentage of the population of the industry. When adjustments are made for companies who could not answer the survey, this percentage goes to 50 percent. The survey also captures most firms with over \$1B in revenues and over 1000 employees. Further, it captures producers who account for most of Canada's oil sands production and announced projects. Production from oil sands is expected to account for a significant share of Canada's oil production. Oil sands production has attracted significant interest here in Canada and from outside of Canada. The survey is considered highly representative of the industry in that this group of firms account for most of the industry's revenues, production, and employment.

Further, industry associations were very helpful in providing advice and endorsing the circulation of the questionnaire. There was excellent support from industry associations including the Canadian Association of Petroleum Producers, the Petroleum Council of Canada, and the Heavy Oil Association. The telephone was the most effective tool in soliciting the cooperation of firms.

The study examined 20 drivers of innovation of companies involved in exploration, development, and production of the upstream petroleum industry and the impact of specific technologies on key performance parameters. The study examined the following three modes of technological innovation of the OECD's *OSLO Manual*: i) acquisition of advanced modern equipment; ii) acquisition of advanced processes; and iii) acquisition of other external knowledge (external R&D, patents, inventions licences, packaged software, trademarks, non-patented knowledge, disclosures, etc.).

The following six types of relatively recent and major technologies are examined in exploration, development, and production: 3D/4D seismic; horizontal (directional) multi-bore wells; field recovery (e.g., enhanced recovery methods, CO₂ injections, and advanced pumping and production techniques); advanced oil sands processes (e.g., SAGD); transportation and transshipment; and sustainable development and environmental technologies (e.g., for reducing CO₂ emissions, natural gas flaring, and oil spillage). The data was analysed through descriptive analyses, principal component analysis, and regression analyses.

The drivers that were found to be the most important are increasing productive capacity, increasing productivity, reducing development costs, meeting environmental regulations, and improving success ratios. Collaboration is important to the sector, and agreements with competitors and suppliers are ranked as most important. The main reason for collaboration is to gain access to external knowledge. The next most important drivers include reducing environmental impacts, reducing transportation and transshipment costs, and improving community relations. Fluctuations in oil and natural gas prices and reducing greenhouse gas emissions were among the least important drivers.

The results show that the sector relies more heavily on investment in advanced machinery and equipment than on internal R&D. A key implication from this is that R&D is not the best indicator of innovation within the upstream petroleum industry. This does not mean that R&D is unimportant to the sector. Instead, it should be recognized that R&D is embedded in advanced machinery and equipment and in advanced processes.

Horizontal wells and 3D/4D seismic stand out as the most important technology in exploration and development, and advanced field recovery technology in production activity. The use of horizontal wells was also the highest. The high use of 3D/4D and horizontal wells suggest that firms are combining the use of these two technologies to efficiently develop their oil and natural gas reservoirs. When oil sands technology is examined with respect to oil sands operators alone, it was found to have the highest mean value of all technologies used.

The results of the study show that there is a strong relationship between the application of technologies and performance. The results demonstrate that firms have improved performance in several ways through reduced costs, increased productive capacity, productivity, and other factors that improve performance such improved exploration success, and improved targeting of oil and gas reserves. Large and integrated firms had higher use of all six technologies and experienced higher performances with these technologies.

Government tax incentives (e.g., SR&ED) is important in spurring R&D. However, it should be noted that the sector use of the program appears quite low. Acquiring advanced machinery and equipment in the sector is correlated with fiscal policy.

It would be worthwhile to undertake other studies in this sector:

- It would be worthwhile for future studies to undertake international comparisons with respect to the use of incentives for innovation and government funding in the upstream sector. Future research should also be undertaken to examine whether

collaboration with industry and government differs from that of other sectors and other countries.

- This study could also be expanded to examine, for example, whether some of these results of this study hold true for the U.S. industry, where similarities exist. A larger sample may permit the use of more sophisticated statistical techniques.
- In discussion with industry, experts pointed out that future challenges include water, specialized skills shortage, the need to reduce energy intensity (energy use per unit of production) in the area of oil sands development, and the reduction of greenhouse gas emissions. It would be worthwhile examining how these factors could impact on long term oil and natural gas production in Canada.
- Although the geopolitical situation has been a key influence in crude price behaviour, there are significant interests in improvements in technology to develop higher cost sources. On a world scale, Canada is a relatively small oil producer and Canadian firms are price takers. A study is needed to examine the potential for small producers, such as Canada, to use technological breakthroughs to influence price determination and oil security balance. This is of particular interest to Canada given its vast oil sands resources.
- A study to further examine the role of government in the sector could be undertaken by looking at a number of specific technologies which required the involvement of

government and industry. The impact of these technologies can be assessed and the key success factors of collaboration with respect to specific projects where there has been cooperation with industry and government can be studied.

- It may be worthwhile to examine how service companies work with firms in the upstream sector to develop technologies and introduce new technologies to the upstream sector and share the risks and benefits in the development and use of technologies.
- It may be worthwhile to examine alternatives to natural gas use. (e.g., nuclear, and renewable energy sources) in meeting increasing oil sands development requirements.

The study has several broad implications with respect to the application of technologies:

- Without the adoption of major technologies, costs would have been substantially higher and productive capacity and productivity much lower. This study also contributes to the view that resources should not be treated as a fixed stock but as flow which can be improved.
- The environment is an important driver of innovation, particularly environmental regulation. Providing the right mix of regulation and leaving firms to undertake innovation may result in favorable impacts.

- Increasing R&D tax incentives may not necessarily have an increased direct impact on innovation in exploration, development, and production compared to other types of firms in the economy. The innovation impact, however, may be increased indirectly through the acquisition of imbedded R&D.
- Collaboration among firms and with government can be useful to address specific industry problems. Government's role will continue to be important in developing pre-competitive technologies for achieving public policy goals.
- Technology can play an important role in Canada becoming an "energy superpower" and more importantly a clean "energy superpower" and contributing to energy security in Canada and in the U.S.

A large number of executives expressed interest in the study. Companies that answered the questionnaire expressed interest in the results. Approximately 80 percent of the companies expressed interests in obtaining a copy of the results. Several industry associations and government officials also expressed interests in the study as well. The Canadian Association of Petroleum Producers expressed interests in the study and asked the members of a newly formed Innovation Committee to support the research. As also noted earlier, several industry associations were very helpful in assisting with the survey including the Energy Council of Canada and the Heavy Oil Association of Canada. Members of other associations who were

non-operators were also very helpful – including CEPA, CAODC, PTAC, and the staff of NEB, Alberta Energy, and NRCan

It is expected that this study will contribute to the literature in several ways, including how innovation takes place in the upstream sector, the influence of key technologies, the role of collaboration, and the impact of government policies. Lesser emphasis on R&D should not be considered as being non-innovative. The acquisition of advanced machinery and equipment, advanced processes, and other external knowledge includes embedded R&D. Finally, although the thesis is highly representative of the industry, one should be careful in generalizing the findings of the study to other sectors of the economy.

GLOSSARY OF TERMS

Barrel of Crude (bbl)	-	A barrel, a measure for oil is 42 U.S. gallons per barrel or 35 imperial gallons (0.159 cubic metres or 158.99 litres).
Brundtland Commission	-	The <i>World Commission on Environment and Development</i> (WCED), known by the name of its Chair Gro Harlem Brundtland, was convened by the United Nations to prepare an Environmental Perspective to the Year 2000 and beyond.
CAODC	-	Canadian Association of Oil Drilling Contractors.
CAPP	-	Canadian Association of Petroleum Producers.
CBOC	-	Conference Board of Canada.
Coalbed methane	-	Coalbed methane (CBM) is natural gas trapped in deep coal beds or coal seams (not easily accessible and associated with high costs of production).
CO ₂	-	Carbon Dioxide.
Conventional Oil	-	“Conventional crude oil” usually refers to light, medium and heavy crude that is a traditional source of most Canadian oil production. Conventional and non-conventional oil is usually differentiated by method of extraction and location – crude oil recoverable from a well using standard production methods.
CEPA	-	Canadian Energy Pipeline Association.
Crude oil	-	Crude oil is a naturally occurring mixture of hundreds of different hydrocarbon compounds trapped in underground rock. These hydrocarbons were created millions of years ago when ancient marine life or vegetation died and settled on the bottoms of streams, lakes, seas and oceans, forming a thick layer of organic material. Sediment later covered this layer, applying heat and pressure that “cooked” the organic material and changed it into the petroleum we extract from the ground today.
Crude Oil Use	-	Crude oil provides nearly all of our transportation fuels and is the raw material for hundreds of other products ranging from axle grease to roofing shingles.
CSLS	-	Centre for the Study of Living Standards.

Development Well	-	A development well is a well drilled with the object of further exploiting the “pay” horizon of a pool within an area which has already been proved capable of production from this pool. Development wells are drilled after the exploratory wells and appraisal wells (particularly important offshore to establish optimum location of the platform) have been completed.
Directional Drilling	-	Horizontal wells – Drilling at an angle instead of vertically in offshore such as Hibernia, multiple wells have been drilled from the central platform.
Drill-stem test	-	Production tests run on potential pay zones as they are encountered during drilling.
Enhanced recovery	-	Involves the use of artificial drives mechanisms, such as waterflood, CO ₂ and steam injections.
Exploratory Wildcat	-	Is a well located at a relatively considerable distance outside the limits of known pools and drilled in geological environment where hydrocarbons have not yet been discovered.
Farm out Agreements	-	An operating company with a petroleum lease or concession may “farm out” all or a portion of its property to another operator in return for various compensation.
GHGs	-	Greenhouse Gas Emissions.
Heavy Oil	-	Generally, a crude having a density greater than 900 kg/m ³ . Heavy oil requires additional pumping or dilution to flow through well and pipelines and when refined, it produces proportionally more heating oil and a smaller amount of transportation fuels.
IEA	-	International Energy Agency. The IEA was established in 1974 within the framework of the OECD to implement an international energy program. The organization comprises of 24 member countries of the OECD. The basic aims of the IEA are to: maintain and improve systems for coping with oil supply disruptions; promote rational energy policies in a global context through cooperative relations with non-member countries, industry and international organizations; operate a permanent information system on the international oil market;

improve the world's energy supply and demand structure by developing alternative energy sources and increasing the efficiency of energy use, and assist in the integration of environmental and energy policies.

EIA	-	Energy Information Administration / US Department of Energy.
ICT	-	Information and Communications Technology (ICT)
In-Situ Recovery	-	The process of recovering crude bitumen from oil sands other than by surface mining.
Kyoto Protocol	-	In 1997, in Kyoto, Japan, 159 countries negotiated a treaty setting out legally binding reduction targets for six greenhouse gases (carbon dioxide (CO ₂), methane (CH ₄), nitrous oxide (N ₂ O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF ₆). The Kyoto Protocol came into effect in February 2005 it sets binding targets for developed countries to reduce greenhouse gas emissions by 5.2 percent below 1990 levels by 2008 to 2012. CO ₂ account for the bulk of the emissions. Canada committed to reducing greenhouse gas emissions by 6 percent below 1990 levels.
Light Oil	-	Generally a crude having a density less than 900 kg/m ³ . Light oil flows easily through wells and pipelines and, when refined produces a large quantity of fuels such as gasoline, diesel, and jet fuel.
Lloydminster Blend	-	Lloydminster blend is a heavy crude oil produced in Canada which is the benchmark grade crude oil for Canadian price quotations.
Natural gas	-	Natural gas is a mixture of hydrocarbons, mainly methane, which is both colourless and odourless. Water, oil, sulphur, carbon dioxide, nitrogen and other impurities may be mixed with the gas when it comes out of the ground. Natural gas is found in reservoirs beneath the surface of the earth. The areas where the gas is trapped are referred to as pools; the natural gas molecules are actually held in small holes and cracks throughout the rock formation.
NEB	-	The National Energy Board.

Non-conventional Crude Oil	-	Crude oil that is classified as non-conventional crude oil (e.g., bitumen) because it requires non-standard methods of production.
NRCAN	-	Natural Resources Canada
OPEC	-	Organization of Petroleum Exporting Countries consists of 11 countries - Saudi Arabia, United Arab Emirates, Kuwait, Qatar, Algeria, Venezuela, Nigeria, Indonesia, Iraq, Iran, Libya. OPEC accounts for 78 percent of world oil reserves of more than one trillion barrels and 40 percent of production.
OECD	-	Organisation of Economic Cooperation and Development.
PTAC	-	Petroleum Technology Alliance Canada.
Roughneck	-	Member of a drilling crew involved in oil and/or gas exploration and development.
Recovery Factor	-	The fraction of a reservoir's original oil in place (OOIP) or original gas in place (OGIP) that will be recovered.
Reservoir	-	A reservoir is a porous and permeable underground rock formation containing a natural accumulation of crude oil and/or gas that is confined by impermeable rock or water barrier. Most reservoir rocks are limestone, dolomite, sandstones, or a combination of these. The three basic types of reservoirs are oil, natural gas, and condensates.
SAGD	-	Steam Assisted Gravity Drainage (used in in-situ recovery).
Supply Costs	-	Expresses all the costs associated with resource exploitation as an average cost per unit of production over the life of a project. It includes capital costs associated with exploration, development, and production as well as operating costs, taxes, royalties, and producer rate of return.
Upgrading	-	Upgrading is the process of converting bitumen or heavy crude oil into a higher quality of crude oil either by the removal of carbon (coking) or the addition of hydrogen (hydro-processing).
Upgraded crude oil	-	Generally refers to crude bitumen and heavy crude oil that have undergone some degree of upgrading (commonly synonymous with synthetic crude oil).

- WCSB - Western Canadian Sedimentary Basin (WCSB) covers 580, 000 square miles extending over four western provinces and includes part of the Northeast British Columbia. It contains most of the known oil reserves in Canada.
- WTI - West Texas Intermediate – is a light sweet crude oil, produced in the United States, which is the benchmark grade of crude oil for North American price quotations.
- Joule (J) - Heating unit (1000 joules = 1 BTU).

Source: Alberta Chamber of Resources (2004); Brundtland Commission (1987); Conaway, (1999); IEA (1997), National Energy Board (2006a); Natural Resources Canada (2006); Sproule Associates (1994); and U.S. DOE/EIA (2007b).

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Appendices

Appendix 1

Table AP 1.1**World Crude Oil Production (Thousands of Barrels Per Day)**

	1965	1975	1980	1990	1995	2000	2005
USA	9014	10008	10170	8914	8322	7733	6830
Canada	920	1735	1764	1965	2402	2721	3047
Mexico	362	806	2129	2977	3065	3450	3759
Total North America	10296	12549	14063	13856	13789	13904	13636
Total S. & Cent. America	4334	3698	3747	4507	5782	6813	6964
Total Europe & Eurasia	5648	10992	15086	16099	13822	14942	17534
Iran	1908	5387	1479	3270	3744	3818	4049
Iraq	1313	2271	2658	2149	530	2583	1820
Kuwait	2371	2132	1757	964	2130	2104	2643
Oman	-	341	285	695	868	959	780
Qatar	233	437	476	434	461	855	1097
Saudi Arabia	2219	7216	10270	7105	9127	9511	11035
Syria	-	192	158	407	596	548	469
United Arab Emirates	282	1696	1745	2283	2362	2626	2751
Yemen	-	-	-	182	351	450	426
Other Middle East	61	62	55	52	52	48	48
Total Middle East	8387	19733	18882	17540	20222	23501	25119
Total Africa	2240	5047	6225	6725	7112	7844	9835
Total Asia Pacific	898	3806	4943	6743	7375	7936	8000
<u>Of which OECD</u>	<u>10779</u>	<u>13670</u>	<u>17135</u>	<u>18837</u>	<u>20734</u>	<u>21514</u>	<u>19763</u>
<u>OPEC</u>	<u>14386</u>	<u>27168</u>	<u>27249</u>	<u>24629</u>	<u>27654</u>	<u>31393</u>	<u>33836</u>
<u>Non-OPEC (Excludes FSU)</u>	<u>12559</u>	<u>18741</u>	<u>23580</u>	<u>29275</u>	<u>33151</u>	<u>35535</u>	<u>35408</u>
<u>Former Soviet Union (FSU)</u>	<u>4858</u>	<u>9916</u>	<u>12116</u>	<u>11566</u>	<u>7297</u>	<u>8013</u>	<u>11844</u>

* Includes crude oil, shale oil, oil sands, and NGLs (natural gas liquids - the liquid content of natural gas where this is recovered separately) but excludes liquid fuels from other sources such as coal derivatives.

Source: *BP Statistical Review of World Energy 2006*,
([BPhttp://www.bp.com/productlanding.do?categoryId=91&contentId=7017990](http://www.bp.com/productlanding.do?categoryId=91&contentId=7017990)).

Table A P 1.2

Paradigms of Resource Development

	Old Paradigm	New Paradigm
Source of Technology	In-House	Leverage and Collaborate
Project Prioritization	Technology Push	User Needs
Motive	Own It	Use It

Source: NPC, 1995.

Figure AP 1F.1

Vertical Well

Source: NRCan - internal document.

Figure AP 1.F2

SAGD Process – Shows Two Horizontal Wells

Source: Petro Canada

Oil Sands Projects and Location

LEGEND

In Situ Projects ▲	Operator	Mining Projects ○	Operator
Orion	BlackRock Ventures	Muskeg River	Albian Sands (Shell/Chevron/Western Oil Sands)
Kirby	Canadian Natural Resources	Jackpine Mine	Albian Sands (Shell/Chevron/Western Oil Sands)
Wolf Lake/Primrose	Canadian Natural Resources	Horizon*	Canadian Natural Resources
Surmont	ConocoPhillips/Total	Kearl Lake	Imperial Oil
Great Divide	Connacher Oil and Gas	Suncor Bose Mine	Suncor Energy
UTF (Dover)	Devon Energy	Millennium	Suncor Energy
Jackfish Creek	Devon Energy	Syncrude Base Mine	Syncrude Joint Venture
Borealis	EnCana	Aurora	Syncrude Joint Venture
Christina Lake	EnCana	Northern Lights	Synenco
Foster Creek	EnCana	Fort Hills	Petra-Canada/UTS Energy/Teck Cominco
Caribou	Husky Energy	Joslyn Creek	Total E&P Canada
Sunrise	Husky Energy		
Tucker Lake	Husky Energy		
Gold Lake	Imperial Oil		
Hongington	Japan Canada Oil Sands (JACOS)		
Christina Lake	MEG		
Long Lake	OPTI/Nexen		
Lewis	Petra-Canada		
MacKay River	Petra-Canada		
Meadow Creek	Petra-Canada/Nexen		
Cadotte Lake	Shell Canada		
Firebag	Suncor Energy		
Joslyn Creek	Total E&P Canada		

Major Primary Production Areas ♦
SEAL
Pelican Lake
Lindbergh
Frog Lake
Brintnell
Bonnyville
Beaverdam

* Includes plans for both in situ and mining

Appendix 2

Table AP 2.1

Top Twenty Countries in the World in Terms of Crude Oil Reserves

Rank	Country or Region	Estimated Crude Oil Reserves	
		Billions of Barrels	Reserves to Production Ratio (years)
1	Saudi Arabia	267	77
2	Canada	179	213
3	Iran	133	94
4	Iraq	115	171
5	Kuwait	102	117
6	United Arab Emirates (UAE)	98	109
7	Venezuela	80	103
8	Russia	59	18
9	Libya	39	65
10	Nigeria	36	41
11	United States	21	11
12	China	18	14
13	Qatar	15	52
14	Mexico	13	11
15	Algeria	11	23
16	Brazil	11	19
17	Kazakhstan	9	25
18	Norway	8	8
19	Azerbaijan	7	48
20	India	6	24

Note: The U.S. reserves are estimated at 21 billion barrels. This is well above Canada's estimated conventional reserves. Only recently, have oil sands reserves have been included in Canada's reserves estimates.

Source: Information extracted from the *Oil and Gas Journal* (Penwell, 2005), Volume 103, No. 47.

Source: See also IEA, (International Energy Agency). 2006a. *World Energy Outlook*, OECD Head Office Publications, Paris.

Table AP 2.2

Natural Gas Price Nymex/Henry Hub

Years	\$U.S./Mcf	\$Cdn/Mcf
1991	1.55	1.69
1992	1.82	2.12
1993	2.13	2.61
1994	1.90	2.48
1995	1.64	2.13
1996	2.57	3.32
1997	2.59	3.41
1998	2.16	3.05
1999	2.27	3.19
2000	3.89	5.50
2001	4.27	6.24
2002	3.22	4.79
2003	5.39	7.19
2004	6.14	7.55
2005	8.62	9.83
2006	7.23	7.79

Source: NRCan, Natural Gas Division.

Table AP 2.3

Canada's Natural Gas Reserves and Potential

	Remaining Proved Reserves ⁽¹⁾	Contingent Resources ⁽²⁾	Undiscovered Resources ⁽³⁾	Total Remaining Resources ⁽⁴⁾
WCSB				
Alberta	40.9	0	56.6	96.1
British Columbia	12.3	0	21.4	34.2
Saskatchewan	3.3	0	0.9	3.6
Southern Territories	0.4	0	5.9	6.4
Unconventional	0	0	80	80.0
Total WCSB	56.9	0	164.9	220.3
East Coast (Offshore)	0.5	13.7	77.9	90.7
West Coast	0	0	17.1	17.1
Northern Canada				
Mackenzie Beaufort	0	9.0	51.5	60.5
Arctic Islands	0	11.7	28.0	39.7
Other	0	0.7	15.1	15.8
Total Northern Canada	0	21.4	94.6	116.0
Others (Ontario, Gulf of St. Lawrence)	.5	1.7	2.0	2.6
Total Canada	57.9	36.8	356.5	446.7

- Notes:
- (1) Proved reserves are reserves close to pipelines and can be produced in today's market conditions.
 - (2) Contingent resources have been found by drilling but are in remote regions and cannot be currently connected to markets (e.g. Mackenzie Delta, and Deep Panuke, off Nova Scotia).
 - (3) Undiscovered resources are those resources estimated to be found in the future.
 - (4) Total remaining resources are the sum of (1), (2) and (3).

Source: NRCan, Natural Gas Division, Canadian Association of Petroleum Producers (Proved Reserves); and the National Energy Board.

Table AP 2.4

**Top Ten Countries in the World and
Canada in Terms of Natural Gas Reserves**

Rank	Country or Region	Estimated Natural Gas Reserves	
		Trillions of Cubic Feet	Reserves to Production Ratio (years)
1	Russian Federation	1682	78
2	Iran	993	N/A
3	Qatar	895	N/A
4	Saudi Arabia	250	96
5	United States	209	11.3
6	Venezuela	152	N/A
7	Netherlands	106	N/A
8	Turkmenistan	101	N/A
9	Indonesia	92	36
10	Australia	91	67
	Canada ⁽¹⁾	58.7	8.9

Source: BP Statistics - <http://www.bp.com/productlanding.do?categoryId=6848&contentId=7033471>.

Note: (1) Canada ranks 16th in the world in terms of reserves.

Appendix 3

A REVIEW OF CANADA'S INNOVATION PERFORMANCE AND POLICY ENVIRONMENT

As noted in the last section of Chapter 2, firms do not operate in an environment exclusively defined by markets, industry structures, and market opportunities. Instead, they operate in a political, legal, and fiscal context often influenced by government actions (Coombs, 1987). Furthermore, the role of government in science and technology has been increasing in industrialized countries. This Appendix discusses the importance of Canada's policy with respect to innovation, Canada's productivity gap with the United States, Canada's R&D performance relative to other countries, and government policies and support for innovation. This Appendix underscores the fact that the productivity gap with the United States is a key concern for Canada and that innovation performance and productivity are priorities of the government.

A3.1 Productivity Gap with the United States

Canada's economic performance continues to be strong relative to other economies. This is reflected in several indicators, namely, strong GDP growth, low interest and inflation rates, good job creation (and low unemployment), budget surpluses, and debt reduction over recent years (IMF 2003, Finance Canada, 2006). Canada is also the only G-7 country to maintain a financial surplus despite the global slowdown (Finance Canada, 2003). The Canadian dollar

has appreciated more than 30 percent over the past year, reflecting favourable economic fundamentals in Canada (including significant improvements in commodity prices, particularly oil and natural gas) and the relative weakness of the American dollar (\$US) against other major currencies (TD Economics, 2003 and TD Economics, 2006). Canada, unlike the United States, has a current account surplus and has been reducing its reliance on foreign debt relative to GDP. Key factors that underlie Canada's strong performance include sound macro underpinnings, fiscal restraint, and trade liberalization (IMF, 2004; OCED, 2003a; Martin and Porter, 2001; Finance Canada, 2006).

In spite of Canada's strong economic performance, however, its GDP per capita, a key measure of living standards, is about 16 percent below that of the United States. This "prosperity gap" reflects labour productivity differences¹ (CSLS, 2003b; Institute for Competitiveness and Prosperity (ICP), 2004). Labour productivity in the United States is not only higher but has grown at a faster rate. Data from the CSLS (2004, Statistics Canada, 2005) show that U.S. labour productivity exceeded that of Canada over the 1989-2002 period (1.64 percent versus 1.58 percent). The higher productivity growth experienced in Canada over the 1995-2002 period (2.18 percent) was also exceeded by that in the United States.

¹Productivity is defined as the value of outputs produced using a fixed amount of the input factors of production (CSLS, 2003a). It is usually expressed in terms of labour (output per worker), and capital (per \$1000 of capital stock). Total factor productivity (TFP) or multi-factor productivity (MFP) measures productivity for more than two inputs and is important for gauging the efficient use of resources.

An increase in innovation performance is one of the key policy goals of the Government of Canada, as reflected in *Canada's Innovation Strategy* (released in 2002), *Budget 2003*, and the *Speech From the Throne*, 2004. Canada's lower level of innovation is considered to be one of the key reasons for our low productivity and standard of living relative to those of the United States, Canada's largest trading partner. Nicholson (2003) notes that weak productivity growth has been the Achilles' heel of the Canadian economy for the past 25 years. Rising productivity enables companies to pay higher wages, keep costs down, and increase profitability, and it is the main route to more and better jobs, a higher quality of life, and a higher standard of living.

There are a number of ways of increasing productivity (OECD, 2003a). One method is to improve the quality of labour through increased and better education and training. Another is to increase the amount of capital (often as machinery and equipment) used in production. Analysis for Canada and the U.S. has shown that much of the increase in labour productivity over the post war period is attributable to increasing the capital stock. It is becoming apparent that using more capital is not sufficient to keep Canada competitive, but that we must increase the technology embedded in the capital stock by becoming more innovative (CSLS, 2003b). Figure A3.1 of this Appendix shows innovation as a key force driving productivity. Becoming more innovative increases the productivity of both capital and labour, thus raising the standard of living while maintaining and improving Canada's competitive position in world markets.

A 3.2 Canada's R&D Performance

In 2003, total R&D expenditures in Canada totalled \$12B.² Estimates by Statistics Canada (2003) show that the best performance was in the business enterprises sector, which contributed 54 percent of all Canadian R&D. Higher education accounted for 33 percent, governments for 12 percent, and private non-profit organizations the remaining 1 percent. About two-thirds of the industrial R&D in Canada is performed by a small number of companies. Although the degree of concentration is high, it has decreased over the past 30 years (SC, 2003). Of the 8,893 companies that reported performing R&D in 2001, 100 (or 1.1 percent) accounted for 64 percent of the total R&D performed.

Nicholson (2003) maintains that it is difficult to fault Canada for its achievements in macroeconomic policies, human capital development, and trade exposure, but there is still room for improvement. He argues, however, that the areas that should be considered for the greatest level of improvement in Canada are innovation and productive investment (includes +new technologies³). The CBOC (2001b) argues that, since investment in technology boosts

² Of the total expenditures, Communications and Equipment accounted for 17 percent, Computer System Design and related services 8 percent, Aerospace and Parts 7 percent, Pharmaceutical and Medicine 9 percent, Semiconductor and Electronic Components 7 percent, Information and Cultural industries 5 percent, Scientific Research and Development Services 5 percent, and other industries 42 percent.

³ Nicholson (2003) assigned a three star rating to sound macro policies, human capital, and exposure to trade. Productive investment receives a two star rating and innovation receives a questionable one star rating.

productivity, the productivity gap can be explained in part by under-investment in R&D by Canada's private sector. The World Economic Forum (WEF, 2003) *Global Competitiveness Report* demonstrates that technological innovation is a critical factor for productivity growth and standard of living.⁴

Canada's expenditure on R&D, measured as a share of GDP, stands at the mid-range of those of all OECD member countries. In 2001, OECD countries spent 2.3 percent of their GDP on R&D (GERD). Canada spent 1.9 percent and ranked 13th in this group of countries (Figure A2, Appendix 1).

In 2001, business expenditure on R&D (BERD) was 1.5 percent of GDP, placing Canada 15th (about the middle of the pack) among the 30 OECD countries (OECD, 2003d). During the 1995-2001 period, growth in R&D expenditures in Canada (5.6 percent) outpaced the OECD average (4.7 percent), the United States (5.4 percent), the European Union (3.7 percent) and Japan (2.8 percent). However, Canada fell well below Finland (11.3 percent), which ranks as number one in the world on the WEF's 2003 *Global Competitiveness Index*. Furthermore, the number of researchers per capita in Canada is lower than that in the G-7 countries and the United States. Rates of issuing new patents are also relatively low, and so is overall investment in machinery and equipment. Canada does have many strengths, however: its scientific publications are widely cited; it is a leader in the adoption of information and

⁴ WEF's *Global Competitiveness Report* develops a (*Growth Competitiveness Index (GCI)*), which is utilized in the analyses of an economy's potential for economic growth and its current economic performance. The index is heavily weighted to the level of technological innovation. The index is based on Finland ranked first, followed by the US, Sweden, and Denmark on the GCI. Canada fell to 16th place on the GCI.

communications technology (ICT), including broadband; it is considered the second most connected country in the world – gold-medal standing (CBOC, 2003); and it is well integrated with the United States in terms of business. According to the CBOC’s study in bench-marking Canada against other countries, Canada ranked in fifth place in innovation.

The World Economic Forum (WEF) *Growth Competitiveness Index* is heavily weighted towards technological innovation, thus underscoring the importance of innovation as a critical factor for productivity, competitiveness and standard of living growth. The WEF maintains that the U.S. good performance is attributable to its strong technological base and to a pipeline of innovation that is second to none. Furthermore, the U.S. has companies that are aggressive in adopting new technologies and in spending heavily on R&D. CBOC (2001b) argues that given that investment in technology boosts productivity, it is plausible to argue that investment in innovation improves the standard of living of a country. It is plausible, therefore, that the gap between the US and Canada can partially be explained by under-investment in R&D in Canada’s private sector.

A 3.3 Canada’s Innovation Policy

As noted earlier, government plays a key role in innovation and most industrialized countries have recognized the importance of innovation. The last two federal budgets also highlight the importance of productivity and investment in innovation. The Government of Canada supports innovation in several ways, among which a Statistics Canada (1999) report identifies

R&D tax credits, R&D grants, venture capital support, technology support, information services, and support for training.⁵ The current government's election platform, released in 2006 (*Stand Up for Canada*, 2006, p.17) stated that it will: "Recognize the success of the Scientific Research and Experimental Development (SR&ED) tax credit in spurring private investment in research and development and work with stakeholders in all fields of research and various industry sectors to explore expanding this tax credit."⁶

The government has long been involved in innovation in Canada. The National Research Council was established in 1916 to ensure a consistent structure to support research. The federal government's substantive policy commitment to innovation policies in Canada, however, began largely in the 1970s in response to research showing that technological progress was a key determinant of economic prosperity (e.g., that of Nobel Prize winning economist, Robert Solow) and continued in the following decades. The 1980s and 1990s saw

⁵CBOC (2000) notes that the Scientific Research and Experimental Development (SR&ED) program is Canada's largest federal program that promotes industrial R&D. The program is about \$2.4B in recent years. The Program is administered by the Canada Revenue Agency (CCRA).

⁶Conservative Party of Canada, *Stand Up for Canada: Federal Election Platform*, 2006.

major announcements with respect to R&D and innovation. This trend has continued in the new millennium

The Speech from the Throne (SFT) (2001) stressed the importance of innovation. SFT (2001) also highlighted the resources sector, noting that the Government of Canada will “...promote innovation, growth and development in all parts of the economy, including the agriculture and resource sectors.” Recognizing the importance of innovation and, in response to Canada’s poor performance, the Government of Canada launched Canada’s *Innovation Strategy* in 2002 by releasing the following two papers — *Achieving Excellence: Investing in People, Knowledge and Opportunity* and *Knowledge Matters: Skills and Learning for Canadians*. This approach formed the basis for a national engagement strategy, aimed at raising awareness of the importance of innovation and skills and learning issues, and initiating a dialogue on how Canada can best respond to the challenges of the knowledge-based economy. More than 10 months of consultations, involving over 10,000 Canadians, concluded with a National Summit on Innovation and Learning in November 2002, in Toronto. The Summit brought together more than 500 leaders across the country to take action to make Canada one of the most innovative and skilled countries in the world. NRCan participated in this process through the National Round Table on Innovation and Skills in the Natural Resources Sector and Allied Industries. *Achieving Excellence* argued that investment in R&D yields significant benefits and that successful nations invest strongly in R&D. The strategy proposed a target of having Canada rank as one of the top five countries in terms of R&D performance and to at least double federal investments in R&D by 2010. The strategy highlighted the increasing involvement of government laboratories in partnerships and noted

that it may be appropriate to consider new partnership models across government departments, including other R&D players, and to address key emerging issues, such as security and water safety.

SFT 2004 highlighted the importance of innovation and R&D performance. It also called for action to improve human resources development, science, health, investment, sustainable development, and immigration to raise Canada's standard of living and well-being. Over the 1998-2003 period, Canada provided \$13B of innovation funding. Combined with R&D tax credits, this figure goes to \$15.5B. Two key programs in Canada to promote innovation are: Technology Partnerships Canada (TPC), and the Industrial Research Assistance Program (IRAP). TPC is a technology investment fund that was established to encourage private sector investments and increase the technology base and capabilities of Canadian industry, mainly by investing strategically in innovation and R&D. Similarly, IRAP offers direct technical assistance in the latest technological advances, expertise, and resources, as well as in cost-share financing of innovative technical projects.

According to Canada's *Innovation Strategy*, the private sector needs to strengthen its ability to develop innovations for world markets and adopt leading-edge innovations from around the world. Relatively low levels of investment in R&D, too few strategic technology alliances, and limited pools of capital contribute to Canada's relatively poor innovation performance. The two major goals of Canada's *Innovation Strategy* are to vastly increase public and private investments in knowledge to improve Canada's R&D, and to ensure that a growing number of firms benefit from the commercial application of knowledge. The

Government's targets by 2010 are to at least double the Government of Canada's current investment in R&D and place Canada among to the top five countries in the world in terms of R&D performance. It also aims to make Canada a world leader in the share of private sector sales attributable to new innovations, and to raise venture capital investments per capita to the prevailing U.S. level (IC, 2002). It is interesting to note that for government to encourage innovation in Canada is in line with the funding programs of Canada's major competitors. A key challenge will be to increase spending in the private sector. It is also recognized that innovation does not involve only R&D but also the application and diffusion of technologies and that this is particularly crucial for a small open economy such as Canada.

A 3.4 Scientific Research and Experimental Tax Credit

The competitiveness of Canada's tax system has been under scrutiny recently (McKenzie 2006). The *Tax Competitiveness Report* (Mintz, *et al.*, 2005) argued that there is considerable scope for improvement of Canada's tax competitiveness position particularly with respect to corporate income taxes and other related capital taxes. The report shows that Canada ranks second highest among 36 industrial and major developing countries with respect to marginal effective tax rates on production capital.⁷

One area where Canada is considered to be internationally competitive is with respect to the SR&ED tax incentive system, which provides a tax credit for qualifying SR&ED expenses incurred in Canada. In fact, the system is considered to be the most generous in the world

⁷ The report also shows that the US ranks fourth, China, the highest and Singapore, the lowest.

(Warda, 2003). The SR&ED tax credit system has been in place since the mid 1980s and the basic structure has changed very little during the last two decades. The last public information is from 2000, which indicated that there were 11,000 claimants with an estimated credit claim of \$1.7 in 2003 and \$2.5B for 2005 – the program is Canada’s largest single program supporting business activity (Industry Canada, 2006). Sharpe (2005) argues studies need to be done to understand whether the natural resources sector is making use of the program and the effectiveness in the sector. Large corporations that represent 8 percent of the claimants accounted for 85 percent of the claims.

The criteria for eligibility are that the work must be a systematic investigation or search conducted by experiment or analysis in a field of science or technology. The OECD’s *Frascati Manual* definition of R&D provides the basis for the definition used for SR&ED. Eligible work comprises basic research, applied research, experimental development, and related support work.⁸ The definition used for the SR&ED is covered in the *Income Tax Act*⁹ (Section 248 (1)). Expenditures on buildings and other structures used in the process of conducting R&D do not receive the same treatment but are allowed capital cost depreciation under the capital allowance system. In spite of the generous level of SR&ED, R&D is still

⁸The credit is available to reduce tax otherwise payable in a year or it may be carried forward or back to reduce tax payable in other years (there are some limitations on the carry forward and back provisions). In addition all qualifying R&D costs may also be deducted fully in the year in which they are incurred including capital equipment that would otherwise be deducted under the system of capital cost allowances.

⁹The system provides a 20 percent federal tax credit for R&D (for small business the credit is 35 percent). Most provinces provide additional incentives in the range of 10 to 15 percent. At the federal level, all current eligible expenditures on R&D are immediately expensed. These include wages and salaries for workers engaged in R&D as well as materials and supplies. Immediate expensing is also extended to expenditures on equipment which is used for R&D that would ordinarily be depreciated over time as a part of the capital costs allowance system.

very relatively low in Canada. The U.S. system allows for expenditures on some base level in order to qualify for the credit. Nevertheless, Mintz (2001) shows that, when direct and indirect grants are taken into account, the difference between Canadian and U.S. subsidies to R&D is quite small.

Almost all provinces provide some additional tax credits ranging from 10-15 percent (Quebec has the highest). Alberta is the only major province that does not have an R&D tax credit. A possible explanation is that Alberta actually provides an incentive for oil-and- gas related R&D but does so through its royalty holiday system or other royalty reduction incentives. For example, in areas such as ICT, medical research, and agriculture, the province provides focused tax credits or grants. Another suggestion is that the Alberta government believes that a lower corporate tax rate is a better incentive than targeted credits for R&D and other investments. Recently, a high-level panel has been appointed to examine the fiscal system related to Alberta's energy industry.¹⁰

There is strong interest in understanding whether the natural resources sector takes advantage of the SR&ED. Recently Harris (2005) and McKenzie (2006) have sought to explain the low level of R&D through tax policy. Harris (2005) argues that R&D federal and provincial resources need to be more focussed than those provided by the existing tax credit system. McKenzie (2006) argues that the Canadian approach has been to give on the one hand, by providing generous tax credits targeted at R&D, and to take back on the other hand, by imposing high taxes on the fruits of innovative activity. His basic argument is that tax

¹⁰On February 16, 2007, the Alberta Government announced the establishment of an Expert Panel to examine the province's royalty and tax regimes.

subsidies that lower the cost of R&D as measured by its after tax user costs, reward effort and cause a “push” effect on R&D. High taxes on production – on the fruits of R&D (new products and processes) – punish success. Conversely, low taxes on production reward success (or punish it less) and result in a “pull” effect on R&D. Both “push” and “pull” effects need to be taken into account when evaluating the overall system of R&D.

Figure A3.1: Factors Influencing Productivity

Source: Finance Canada, 2004

Figure A3.2: Canada's Ranking Among OECD Countries - R&D Expenditures

Source: OECD, Science, Technology and Industry Scoreboard, 2003 (based on 2002 data or latest available)

Figure 3A.3: Canada's Ranking in the World in Terms of Patents

Figure A3.4: Total Factor Productivity Growth of the Natural Resources Sector: 1989 - 2000 (Average Annual)

Appendix 4

Addressee

Dear (Name of Addressee),

**PhD Thesis Research Survey Questionnaire - Innovation and Performance:
A Case of the Upstream Petroleum Sector**

My name is Jai Persaud and I am a PhD Candidate in the Sprott School of Business, Carleton University, Ottawa. My area of specialization is technology management. I am also a Senior Policy Advisor at Natural Resources Canada, Strategic Policy Branch. In addition, I have held positions with the National Energy Board and the Alberta Energy Utilities Board. I have graduated from the University of Calgary with a BA. and MA in economics.

I am working towards completing my PhD thesis on innovation and performance of companies in the upstream oil and natural gas sector. A review of the literature shows that firms operate under conditions of fluctuating prices, declining conventional reserves, the development of unconventional sources of supplies and strict environmental and sustainable development constraints. The dissertation should provide valuable insights into innovation of the upstream petroleum sector and also contribute to a better understanding of the innovation system of the natural resources sector and that of Canada as a whole.

I am asking that you kindly participate in this study by completing the attached survey questionnaire. The questionnaire should take about 15 to 20 minutes to complete. The completed questionnaire will be held in **strict confidence**. All information and views will be aggregated so that **no individual or firm will be identified**. The results of this study will be used for academic purposes only. Your completion of this questionnaire will be very helpful to me in completing my research in a timely fashion, and will be sincerely appreciated.

Carleton
UNIVERSITY

**Jai Persaud - PhD Survey Questionnaire: Technological Innovation and Performance –
A Case of the Upstream Petroleum Sector**
Confidential When Completed

This study is for academic purposes and the results will be presented only in an aggregated format.

SECTION A

This section asks questions about the size of your firm, years of operation and nature of the business.

Q 1. Size of firm

a) Please indicate how many direct employees are in your firm:

- ☐ Fewer than 20
- ☐ 20 to 49
- ☐ 50 to 99
- ☐ 100 to 249
- ☐ 250 to 499
- ☐ 500 to 999
- ☐ over 1000

b) Please indicate what was your firm's gross revenues in millions of dollars (\$M) from operations for the past year:

- ☐ \$0 - \$49 M
- ☐ \$50 - \$199 M
- ☐ \$200 - \$499 M
- ☐ \$500 - \$999M
- ☐ \$1000M and above

Q 2. Years of operation of company

Please indicate how many years your firm has been in operation:

- ☐ Less than one year
- ☐ 1 - 4 years
- ☐ 5 - 10 years
- ☐ More than 10 years

Q 3. Nature of business

Is your firm involved in the following activity? **Please check all that apply:**

- ☐ Oil exploration (e.g., geological and geophysical activity, seismic, exploration drilling)
- ☐ Natural gas exploration (e.g., geological and geophysical activity, seismic, exploration drilling)
- ☐ Oil development (e.g., development drilling, seismic, use for field equipment, enhanced recovery)
- ☐ Natural gas development (e.g., development drilling, use for field equipment)
- ☐ Oil production (e.g., oil pumping, gathering,)
- ☐ Gas production (e.g., gas processing, gathering, gas processing)
- ☐ Oil sands production
 - ☐ mining
 - ☐ upgrading
 - ☐ in-situ
- ☐ Coal bed methane gas
 - ☐ development
 - ☐ exploration
- ☐ Refining

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SECTION B

This section asks questions about the drivers of innovation, and innovation activities. **Innovation is defined in this study as the use/adoption of a new or improved technology or process or external knowledge in the upstream crude oil and natural gas sector.**

Q 4. Drivers of innovation

Please indicate, on a scale of 1 to 5, the extent to which each of the following factors have been important in driving innovation in your firm over the past three years where: **1 = not at all important; 2 = somewhat important; 3 = important; 4 = very important; and 5 = extremely important.**

<u>Factors driving innovation</u>		<u>Level of Importance</u>				
1) Reducing unit exploration costs	1	2	3	4	5	
2) Reducing unit development costs.....	1	2	3	4	5	
3) Reducing unit re-placement reserve costs	1	2	3	4	5	
(exploration & development costs divided by reserves added)						
4) Reducing unit operating costs	1	2	3	4	5	
5) Reducing unit wellhead supply cost	1	2	3	4	5	
6) Responding to world crude oil price fluctuations.....	1	2	3	4	5	
7) Responding to well head natural gas price fluctuations.....	1	2	3	4	5	
8) Responding to supply/demand conditions	1	2	3	4	5	
9) Increasing productive capacity	1	2	3	4	5	
(e.g., finding/bringing on additional reserves, new fields, work-overs, in-fill wells, new major projects and expansion to existing ones)						
10) Increasing productivity	1	2	3	4	5	
(e.g., output per well, per dollar (\$) invested, and per employee)						
11) Increasing recovery factors	1	2	3	4	5	
12) Improving success ratios.. ..	1	2	3	4	5	
13) Improving targeting oil and gas reserves.....	1	2	3	4	5	
14) Reducing transportation, transshipment and field gathering costs.....	1	2	3	4	5	
15) Proximity to other companies in the same type of business.....	1	2	3	4	5	
(e.g., synergy, skills availability, sharing infrastructure & competition effects)						
16) Reducing greenhouse gas emissions.....	1	2	3	4	5	
(e.g., CO ₂ to meet Kyoto targets)						
17) Reducing environmental impacts (other).....	1	2	3	4	5	
(e.g., terrain, water, flora, fauna)						
18) Meeting environmental regulations/standards safety (e.g., safety)...	1	2	3	4	5	
19) Improving market shares	1	2	3	4	5	
20) Improving community relations	1	2	3	4	5	

Q 5. Innovation activities

Please indicate the importance of the following modes of innovation activities to your firm over the past three years on a scale of 1 to 5, where **1 = not at all important; 2 = somewhat important; 3 = important; 4 = very important; and 5 = extremely important.**

	<u>Importance of Modes of Innovation Activities</u>				
1) Internal research and development (R&D)	1	2	3	4	5
2) Acquisition of advanced/modern equipment (including software)...	1	2	3	4	5
3) Acquisition of advanced processes (including software)	1	2	3	4	5
4) Acquisition of other external knowledge	1	2	3	4	5
(e.g., external R&D, patents, inventions, licenses, know-how, packaged software, trademarks, non-patented knowledge, disclosures, etc.,)					

SECTION C

This section asks questions about the application of major technologies and their impact on your firm's performance.

Q 6. Use of major advanced technologies in exploration, development and production.

Please indicate to what extent your firm used the following technologies in your operations on a scale of **1 to 5**, where: **1 = not used; 2 = used very little; 3 = used moderately; 4 = used quite frequently; and 5 = used extensively.**

Q 6.1) Exploration (If your firm is not involved in exploration, please go to Q 6.2.)**Use of advanced technology**

a) 3D Seismic and or 4D and other advanced seismic technologies.....	1	2	3	4	5
b) Horizontal (directional) wells, multi-bore	1	2	3	4	5
c) Sustainable development / environmental technologies (e.g., for reducing CO ₂ emissions natural gas flaring reducing, oil spillage, etc.)	1	2	3	4	5

Q 6.2) Development (If your firm is not involved in development, please go to Q 6.3.)

Please indicate to what extent your firm used the following technologies in your operations on a scale of **1 to 5**, where: **1 = not used; 2 = used very little; 3 = used moderately; 4 = used quite frequently; and 5 = used extensively.**

Use of advanced technology

a) 3D Seismic (and 4D) and other advanced seismic technologies.....	1	2	3	4	5
b) Horizontal (directional) wells, multi-bore	1	2	3	4	5
c) Sustainable development & environmental technologies (e.g., for reducing CO ₂ emissions natural gas flaring reducing, oil spillage)	1	2	3	4	5

Q 6.3) Production

Please indicate to what extent your firm used the following technologies in your operations on a scale of **1 to 5**, where: **1 = not used; 2 = used very little; 3 = used moderately; 4 = used quite frequently; and 5 = used extensively.**

Use of advanced technology

a) 3D Seismic (and 4D) and other advanced seismic technologies.....	1	2	3	4	5
b) Horizontal (directional) wells, multi-bore	1	2	3	4	5
c) Advanced field recovery technology (e.g., enhanced oil recovery methods water floods, CO ₂ injections, advanced pumping and production techniques)	1	2	3	4	5
d) Advanced oil sands recovery processes (e.g., SAGD)	1	2	3	4	5
e) Transportation and transshipment technology	1	2	3	4	5
f) Sustainable development & environmental technologies (e.g., for reducing CO ₂ emissions natural gas flaring reducing, oil spillage)	1	2	3	4	5

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Q 7. Impact of advanced technologies in the upstream sector

This question asks how specific technologies impacted key performance parameters in your operations.

Q 7.1) EXPLORATION *(If your firm is not involved in exploration activities, please go to Q 7.2.)*

Please rate the impact of the use of the following technologies on your firms exploration activities over the past three years where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive.

a) 3D (and 4D) and other advanced seismic technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit exploration costs					
Reduce unit replacement costs					
Increase productive capacity (e.g., finding new reserves)					
Increase productivity					
Improve targeting of oil and gas reserve deposits					
Improve success ratios					

b) Horizontal (directional) wells, multi-bore technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit replacement costs					
Increase productive capacity (e.g., finding/accessing new reserves)					
Increase productivity					
Improve targeting of oil and gas reserve deposits					
Improve success ratios					
Increase recovery factors					

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c) Sustainable development & environmental technologies

	Not at all	somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce environmental impact					
Reduce greenhouse gas emissions					
Improve community relationships					
Increase market shares					
Better meet environmental regulations/standards					

Q 7.2) DEVELOPMENT (If your firm is not involved in development activities, please go to Q 7.3.)

Please rate the impact of the use of the following technologies on your firms development activities over the past three years where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive.

a) 3D (and 4D) and other advanced seismic technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit development costs					
Reduce unit replacement costs					
Increase productive capacity (e.g., developing new reserves)					
Increase productivity					
Improve targeting of oil and gas reserve deposits					
Improve success ratios					

b) Horizontal (directional) wells, multi-bore technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit development costs					
Reduce unit replacement costs					
Increase productive capacity					
Increase productivity					
Improve targeting of oil and gas reserve deposits					
Increase recovery factors					

c) Sustainable development & environmental technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce environmental impact					
Reduce greenhouse gas emissions					
Improve community relationships					
Increase market shares					
Better meet environmental regulations/standards					

Q 7.3) PRODUCTION

Please rate the impact of the use of the following technologies on your firms production activities over the past three years where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive.

a) 3D (and 4D) and other advanced seismic technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit supply cost					
Increase productive capacity (e.g., producing reserves)					
Increase productivity					
Improve targeting of oil and gas reserves deposits					

b) Horizontal (directional) wells, multi-bore technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit supply cost					
Reduce unit operating costs					
Increase unit productive capacity					
Increase productivity					
Improve producer netbacks					
Manage production to meet market conditions (just in-time inventory/delivery)					
Increase recovery factors					

Q 7.3) PRODUCTION

Please rate the impact of the use of the following technologies on your firms production activities where **1 = not at all**; **2 = somewhat**; **3 = reasonably**; **4 = substantial**; and **5 = extensive**.

c) Advanced field recovery technology

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit supply cost					
Reduce unit operating costs					
Increase productive capacity					
Increase productivity					
Improve producer netbacks					
Improve market shares					

d) Advanced oil sands recovery processes (e.g., SAGD)

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit supply cost					
Reduce unit operating costs					
Increase productive capacity					
Increase productivity					
Improve producer netbacks					
Improve market shares					

e) Transportation and transshipment technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce unit transportation costs					
Reduce environmental impact					
Increase productive capacity (improve viability of new projects)					

Q 7.3) PRODUCTION (CONT'D)

Please rate the impact of the use of the following technologies on your firms production activities where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive.

f) Sustainable development & environmental technologies

	Not at all	Somewhat	Reasonably	Substantial	Extensive
	(1)	(2)	(3)	(4)	(5)
Reduce environmental impact					
Reduce greenhouse gas emissions					
Improve community relationships					
Increase market shares					
Better meet environmental regulations/standards					

SECTION D

This section asks questions about cooperative agreements (collaborative agreements) and the role of government in influencing innovation in your firm. Cooperative agreements and collaborative agreements involve active participation in joint projects between your firm and other firms and organizations (including federal and provincial governments) in developing advanced technologies and processes for use in any upstream activity.

Q 8. Cooperative agreements and technological application

a) Was your firm involved in collaborative agreements in the past three years:

Yes ☐ No ☐

If no, please skip parts b) and c) of this question.

b) Please indicate, on a scale of 1 to 5, the extent of your firm's collaboration with the following organizations over the past three years where 1 = not at all; 2 = somewhat; 3 = reasonably; 4 = substantial; and 5 = extensive.

1) Universities and colleges	1	2	3	4	5
2) Federal government laboratories (e.g., NRCan at Devon)	1	2	3	4	5
3) Research institutes (e.g., National Research Council)	1	2	3	4	5
4) Provincial/territorial government research institutes	1	2	3	4	5
5) Competitors (e.g., through consortia/joint ventures)	1	2	3	4	5
6) Suppliers of equipment and materials	1	2	3	4	5
7) Foreign companies	1	2	3	4	5

c) Please indicate, on a scale of 1 to 5, the extent to which of the following factors were important in determining the level of involvement in collaboration of your firm in the past three years where 1 = not at all important; 2 = somewhat important; 3 = important; 4 = very important; and 5 = extremely important.

Reasons for co-operation

Level of Importance

1) Sharing costs	1	2	3	4	5
2) Sharing risks	1	2	3	4	5
3) Sharing facilities	1	2	3	4	5
4) Accessing new knowledge	1	2	3	4	5
5) Accessing R&D	1	2	3	4	5
6) Developing new markets	1	2	3	4	5

REQUEST FOR RESEARCH FINDINGS

Please send me a copy of the aggregate findings of this study:

☐ Yes

☐ No

If yes, please complete one of the following:

Please e-mail me a copy of the research findings

-my e-mail address is _____

Please send me a hard/printed copy

-my mailing address is:

(Please write your address below or attach your business card)

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