Adaptation Strategy of Petroleum Industries in Canada's Prairie under Changing Climatic and Economic Conditions

(Final Report)

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EXCUTIVE SUMMARY

Climate change will lead to a number of direct and indirect impacts on petroleum industries in Canada's prairie. Therefore, a challenging question faced by the industry is how they should adapt to the changing climatic conditions in order to maintain or improve their economic and environmental efficiencies. In this study, initial efforts have been made to assess the interrelationships between climate change and petroleum activities in Canada's prairies. Many petroleum-related processes that are vulnerable to climate change are analyzed, the associated impacts assessed. Perceptions of stakeholders to the climate-change impacts and the related governmental policies were investigated through a number of interactions with the related industrial and governmental personnel. The adaptation strategies within petroleum sector and the related policy adjustments within governmental organizations at different temporal stages and spatial locations were studies, with a number of recommendations provided.

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1. INTRODUCTION

Climate change will lead to a number of direct and indirect impacts on petroleum industries in Canada's prairie. For example, receding permafrost due to the warming climate may lead to increased slope instability and soil erosion and thus affect safety of pipelines; sea level rise could damage energy production facilities located near or in the ocean; prolonged summer and shortened winter could have significant impacts on many petroleum-related activities, since some activities can be easily done in summer while the others are more suitable for winter. Some positive impacts may also exist, such as decreased cold weather stress on infrastructure production and processing, and reduced costs for offshore exploration due to longer working seasons and less need to withstand ice loads (Huang et al. 1998). Therefore, a challenging question faced by the petroleum industry is how they should adapt to the changing climatic conditions in order to maintain or improve their economic and environmental efficiencies. The answer to this question could be identified through development of effective decision support for the related adaptation responses, based on the insight of complexities associated with the industrial systems. Many factors need to be considered systematically, such as industrial processes and their vulnerability to climate change, interactions among different system components, potential adaptation measures, and inputs from stakeholders (Yin & Cohen 1994; Huang et al. 1996).

Previously, there were many studies of climate-change impacts and the relevant policy responses. For example, Yin and Cohen (1994) developed a goal programming approach for assessing climate change impacts and identifying regional policy responses. Huang et al. (1998) proposed a multiobjective programming method for land resources adaptation planning under changing climate. Anderson and DiFrancesco (1998) studies the potential impacts of climate warming on hydrocarbon production. More studies in this area can be found in Huang et al. (1994, 1996, 1998), and Yin et al. (1994, 1995). However, there were very few studies of integrated planning for detailed adaptation activities within the entire petroleum sector, leading to lack of effective support for industries and governments to make decisions for relevant actions or policies. Especially, no such research has been reported within the context of Canada's prairie, due mainly to the complexities of this industrial sector, as well as the lack of effective communication between researchers in petroleum-related areas and those of the other areas (e.g. climatological and environmental scientists) (Chakma et al. 1989; Chakma & Islam 1989).

Therefore, the objectives of this project are as follows:

(1) To study petroleum-related processes that are vulnerable to climate change, and to undertake integrated impacts assessment;

(2) To investigate perception of stakeholders to the climate-change impacts and the related governmental policies.

(3) To study the adaptation activities within petroleum sector and the related policy adjustments within governmental organizations at different temporal stages and spatial locations.

2. Petroleum Industry in Western Canada

Oil and gas are among the most economically valuable natural resources located in the prairie region. The exploitation of these resources has been retarded by three factors. The first is the remoteness of the resources from major consuming regions. Any exploitation of these reserves would require transportation either through a very long pipeline or by tanker shipping. The second factor is the harsh climatic conditions in the potential producing regions. Since the richest reserves are located in cold region, cold weather, permafrost, etc, are major impediments to exploration, development, production, and transportation, development, production, and transportation. The third retarding factor is the environmental and cultural sensitivity of the regions where the oil or gas would be produced, as well as regions through which it would have to be transported. Environmental sensitivity arises from the vulnerability and the instability of permafrost landscapes.

In practice, the uncertainties in climate scenarios are such that the oil and gas industry cannot incorporate the positive impact of climate change into current design. Negative impacts, however, would e considered because of the conservative approach adopted by the industry. As a result, then, at present climate change is generally viewed to cause an increase in cost for operations in the prairie region.

2.1. Saskatchewan

Saskatchewan's first commercial crude oil discovery was made in 1944. Many of the major pools in the province were discovered as a result of an intensive exploration effort in the mid 1950's and early 1960's. Heavy and light crude oil is extracted in the Lloydminister, Kindersley-Kerrobert, Swift Current and Weyburn-Esteven districts, and there is significant heavy oil potential in the Kindersley-Kerrobert area. These resources are contained in parts of a north-thinning wedge of Phanerozoic sedimentary rocks deposited in the Precambrian shields in an area known as the Western Canada Sedimentary Basin. Hydrocarbon resources are contained in a number of formations that range in age from Ordovician (505 to 440 million years old) to Lower Cretaceous (120-95 million years old); the most significant reserves are contained in rocks deposited between 360 and 320 million years ago during the Carboniferous Period.

Production & Reserves -- Saskatchewan is the second largest oil producer in Canada after Alberta. The province produces more than 20 per cent of total Canadian oil production. Saskatchewan produced crude oil has a wide range of quality, varying from light sweet crude to heavy sour crude. Crude oil production in 1997 reached an all time high of 23.4 million cubic meters. The increases in production over the past several years can be attributed to the many advances in technology that have taken place in the oil industry, as well as continued strong development and exploration activity. Cumulative oil production from Saskatchewan to December 31, 1997 was 503 million cubic meters. Remaining recoverable reserves at December 31, 1997 were estimated to be approximately 185 million cubic meters. There are about four billion cubic meters of heavy oil-in-place in the west central region of the province which represents the greatest potential for future development. In order to realize the potential of this extensive heavy oil resource base, enhanced oil recovery (EOR) techniques have to be applied. EOR will be needed as well to fully develop the significant light and medium oil resource base. Ultimately, an additional 600 million cubic meters of recoverable oil could be developed in the province using EOR techniques.

Exploration & Development -- Saskatchewan had approximately 24,787 wells listed as being capable of oil production at the end of 1997 (almost 18,000 active wells). It is estimated that approximately 80 to 85 per cent of Saskatchewan's oil potential has already been discovered. Therefore, a large part of the future of our industry is tied to improving recoveries from existing pools. Over 370 oil and gas companies operate in Saskatchewan on behalf of more than 1,800 working interest owners. An increase in drilling was recorded in 1997 with at total of 3,608 oil wells drilled compared to 2,544 in 1996. The first horizontal oil well was drilled in 1987, with a total of 3,110 drilled to the end of 1997. There were 668 horizontal wells drilled in 1997, an increase of 32 per cent from 505 drilled in 1996. Approximately 215 waterflood projects are in operation in Saskatchewan. There are also 12 steam injection projects, three in-situ combustion projects, one polymer injection project and one carbon dioxide project. The horizontal drilling technology significantly improves recovery rates and lowers operating costs for many reservoirs in Saskatchewan, particularly those in the heavy oil areas.

Refining & Upgrading -- The majority of the province's refining capacity is in Regina where Consumers' Co-operative Refineries Ltd. operates a 7,946 cubic meter per day conventional refinery. NewGrade Energy Inc., a joint venture by Consumers' Co-op and the Government of Saskatchewan, completed construction of a heavy oil upgrader in 1988. The Newgrade upgrader is currently operating at full capacity (approximately 8,741 cubic meters per day). A second heavy oil upgrader was built at Lloydminster, Saskatchewan in 1992. This Bi-Provincial Upgrader is operated by Husky Oil and is sourcing approximately equal amounts of heavy oil from Alberta and Saskatchewan. Input to the upgrader currently averages 10,807 cubic meters per day of heavy oil blend (including 954 cubic meters per day of "tops" from Husky's Lloydminster asphalt plant).

Markets for Saskatchewan Oil -- Saskatchewan producers operate within a fully deregulated market environment. About 20 per cent of Saskatchewan's production is currently used within the province. Approximately 60 per cent of Saskatchewan's production is currently exported to the United States. The remainder of Saskatchewan's production is sold in Eastern Canada with a minor amount of oil sold in Alberta. Prices are largely determined by the crude oil market in Chicago. The oil produced in Saskatchewan is largely dependent upon one main pipeline system (Interprovincial Pipe Line) to transport it to market.

Economic Impact of the Oil Industry -- The oil industry represents a major economic force in this province as evidenced by the following statistics for 1997. Revenues from crude oil royalties and taxes and sales of petroleum leases accounted for approximately nine per cent of government revenues. About 3,600 oil wells were drilled and oilfield investment was approximately $1.73 billion. Direct and indirect employment associated with Saskatchewan's oil industry (excluding refining, upgrading, and natural gas activity) now accounts for approximately 19,500 jobs.

2.2. Alberta

Alberta's extensive technology and infrastructure, strong knowledge base and favorable business climate makes it industry leaders in oil and gas. The oil industry is the foundation of Alberta's modern economy. Alberta is one of the world's top energy producers with vast reserves of oil and natural gas. The oil sand deposits in Alberta are the largest in the world. Oil sands contain 1.7 trillion barrels of bitumen, of which 300 billion barrels are currently considered recoverable. In 1998, production from conventional oil, oil sands sources, and pentanes was 1.6 million barrels/day. In 1998, Alberta accounted for 69% of all the energy produced in Canada, 65% of Canada's conventional oil, 80% of Canada's natural gas, and 100% of Canada's bitumen and synthetic crude oil. In 1998, Alberta's oil sales were 59% to the United States of America, 25% within Alberta, 15% to the rest of Canada, and 1% for offshore use (destined for Asia). Alberta also holds an 11% share of the U.S. crude oil market.

Natural Gas -- Natural gas is becoming increasingly important as an energy fuel worldwide. In 1998, Alberta's marketable natural gas deliveries totaled 5.056 trillion cubic feet. In 1998, Alberta's natural gas sales were 49% to the United States of America, 32% to the rest of Canada, and 19% for use within Alberta. In 1998, the production of natural gas liquids (ethane, propane, and butanes) totaled 164.8 million barrels, valued at $1.8 billion. Alberta also holds a 12% share of the U.S. natural gas market.

International Trade -- Alberta is the 18th largest oil producer, world's 2nd largest natural gas exporter, and the 4th largest natural gas producer. With 50 years experience developing oil and gas reserves, Alberta has a history of innovative performance that is world class. Over the last five years, its international trade in goods and services has achieved an average, annual growth of almost 10%. Albertans are known for conducting business with a strong focus on export markets. They trade with over 150 countries. More than 2,000 Alberta businesses are exporting goods and services. Annual sales exceed $34 billion. Its exports are comparable to OPEC countries such as Libya, Indonesia and Kuwait.

Technology R&D -- Alberta is a leader in the development of 3-D geophysical survey methods. Companies around the world use their innovative satellite thermal mapping techniques. They are also well known for our advances in horizontal drilling and production technologies. Their innovative techniques reduce directional drilling costs. And their fully integrated drilling and formation evaluation systems maximize production. Alberta's new casing-while-drilling technologies may revolutionize the industry. Their new hydraulic rig technology uses lightweight, versatile rigs that can operate anywhere, reducing drilling and relocation costs. Alberta companies are even building offshore drilling rigs for the North Sea using lightweight modular units. Alberta successfully applied its creativity and experience to develop the acclaimed Alberta Taciuk Process (ATP). Originally created for the oil sands, this process can recover oil for commercial use, from oil-soaked production fields. It is being used in Australia to extract shale oil.

Alberta's multi-million-dollar research has produced dozens of innovative technologies and processes. These new methods are used to lower the cost of developing heavy oil and sour gas. One example is the revolutionary Steam Assisted Gravity Drainage (SAGD) process. This technique uses two parallel horizontal wells to retrieve super-heavy oil or bitumen. Alberta is also a leader in the safe handling and exploitation of deep, high-pressure sour oil and gas. This includes sour gas clean up, sulphur handling, and inhibiting corrosion.

Alberta is recognized around the world for enhanced recovery techniques for mature reservoirs, as well as for rehabilitation of oil and gas fields. They have an immense amount of advanced expertise on using solvents instead of steam for more efficient extraction, and gas boosters to lift output from marginal wells. Alberta software is used to model the movement of fluids for a wide range of recovery processes, including thermal stimulation. This software is used around the world.

Albertans are well known for their talent in design, procurement, construction, and management of pipelines. They have taken their expertise everywhere from tropical jungles to hard rock alpine passes. They have perfected hot tap technologies for high-pressure gas transmission lines, innovative software and Supervision, Control and Data Acquisition (SCADA) applications for pipeline operations, new computerized pigs to detect corrosion or cracks, and developed new composite reinforced pipelines that weigh less and cost less than conventional pipe. Countries around the world approach Alberta for trenchless pipeline digging technologies, continuous welding technologies, new pipe coatings technologies, and pipeline integrity software to reduce unnecessary digs.

Mitigation of GHG emission **--** Alberta is doing more than simply providing clean energy to the world and helping to reduce global emissions. Its resource development industries are world experts in GHG (greenhouse gas) emission reductions. Alberta has a developed a variety of methods for capturing and disposing carbon dioxide on sites, such as depleted oil wells. Alberta companies are also leaders in developing and using new international market mechanisms. One of these is emission trading to achieve greenhouse gas reductions.

2.3. Manitoba

Oil Reserves **--** As of December 31, 1998, total and remaining proved developed reserves in Manitoba were 37.22 million m^3 and 4.18 million m^3, respectively. In 1998, oil production totalled 634.2 10^3 m^3, down 0.4% from 1997. Average daily production for 1998 was 1 737.5 m^3/d, with exit year production of 1 665.1 m^3/d. Reserve additions in 1998 were $111.6\times10^3\,m^3$, replacing 17.6% of production. The reserve life index at the end of 1998 was 6.6 years, down from 7.4 years in 1997.

The majority of Manitoba's proved developed reserves are in the Lodgepole and Lower Amaranth formations. The Lodgepole accounts for 83% of the province's total proved reserves and 69% of the remaining reserves. While the Lower Amaranth accounts for 9% of the province's total proved reserves and 13% of the remaining reserves. The four largest fields in the province accounted for 84% of the total production in 1998; Virden - 32%, Daly - 20%, Pierson - 18% and Waskada - 14%. Combined these fields contain 95% of the province's total proved reserves and 92% of the remaining reserves.

Reserves reassessment in the major Lodgepole pools in the Daly and Virden fields and the Lower Amaranth in the Waskada field resulted in a reduction in reserves of 134.5 $\times 10^3$ m^3. Significant reserve additions were booked for Mission Canyon and commingled Lower Amaranth/Mission Canyon pools in the Tilston and Pierson fields. Total proved developed reserves increased by 137.2 $\times 10^3$ m^3 or 6.7% in these fields. The reserve additions resulted from positive waterflood response in the Pierson Pool and from successful horizontal drilling in Mission Canyon pools.

Production and Markets **--** Annual oil production in Manitoba was 634 071 m^3 (4.0 million barrels) in 1998. Oil production from the Virden, Daly, Pierson and Waskada Fields accounted for 32%, 20%, 18% and 41% respectively of Manitoba's total production. In 1998, a number of fields showed an increase in production over 1997 including Daly (2%), Lulu Lake (472%), Whitewater (5%), Pierson (30%), Kirkella (40%) and Birdtail (33%). Of the total amount of oil purchased by refiners, approximately 22% was refined in Ontario and 78% went to refineries in the United States.

The total value of oil production during 1998 was $70.7 million, down 33% from 1997. During 1998, the Manitoba government collected approximately $4.6 million in revenues ($1.3 million in Crown oil royalties, $2.6 million in freehold oil taxes, and $0.7 million Crown lease sale bonuses, rentals and fees), resulting in a 37% decrease from 1997. These figures do not include provincial revenue in the form of corporate capital tax, sales tax, municipal tax and corporate and individual income tax. Figures 2.1 to 2.3 show more details of oil production in Canada.

Figure 2.1

Manitoba Crude Oil Production 1988-1998

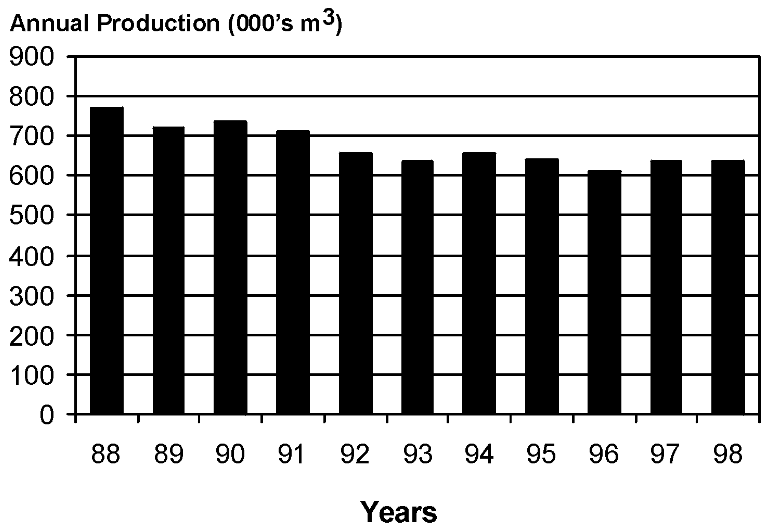


Figure 2.2

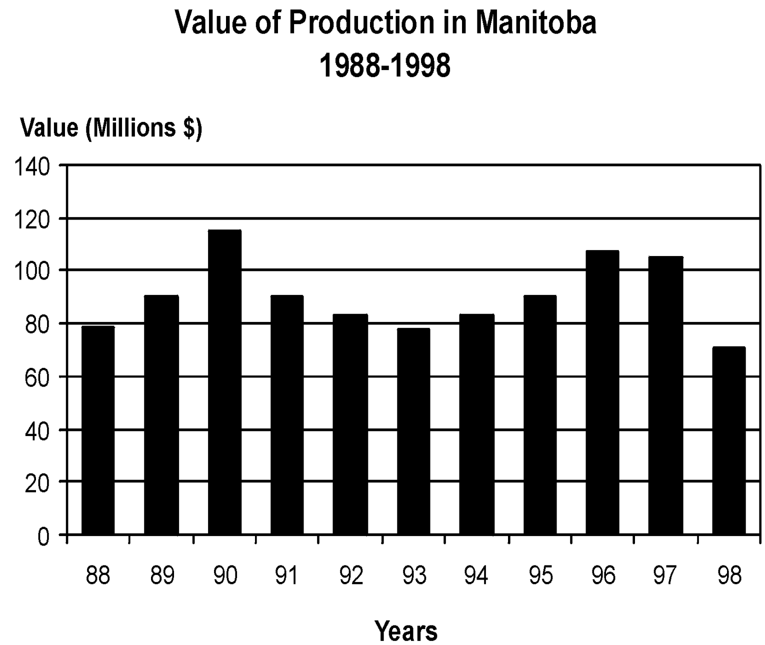
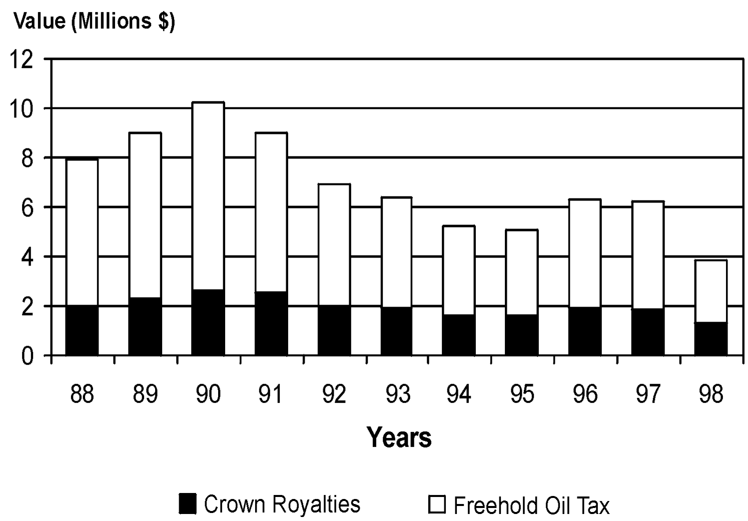

Value of Production in Manitoba
1988-1998
Value (Millions $)
140
120
100
80
60
40
20
0
88
89
90
91
92
93
94
95
96
97
98
Years

Figure 2.3

Crown Royalties and Taxes from Oil Production 1988-1998



3. CLIMATE-CHANGE IMPACTS ON PETROLEUM EXPLORATION AND PRODUCTION

Canada is the world's eleventh largest producer of crude oil. Crude oil activity in Canada today is concentrated primarily in the Western Canada Sedimentary Basin. Alberta, Canada's largest producing province, accounts for about 78 per cent of total hydrocarbon production. Both Saskatchewan and British Columbia are areas of growing activity, producing 18 per cent of total hydrocarbon production. The remaining production comes from Manitoba, Ontario, East Coast offshore and the Northwest Territories. Covering approximately 580,000 square miles, the depth of the Western Canada Sedimentary Basin ranges from near surface in the northeast region to more than four miles in the west near the Rocky Mountains.

In 1999, Canada produced 1.5 million barrels per day of conventional crude oil (which includes both light and heavy conventional crude oil) and pentanes plus (condensate). Approximately 10,500 new wells were drilled during the year 1999. The majority of conventional production in Canada comes from the Western Canada Sedimentary Basin. The Hibernia project offshore Newfoundland averaged close to 100,000 barrels per day in 1999. To the end of 1998, production of 17.3 billion barrels of conventional has been realized in the Western Canadian Sedimentary Basin, from an ultimate potential of 30.9 billion barrels.

The petroleum industry plays a key role in Canada's $40.5 billion energy sector. In 1995, the production of crud oil and natural gas, the sale of refined petroleum products and pipeline transportation was together worth $23.1 billion. This represents 4.3 percent of Canada's gross domestic product and nearly 200,000 jobs. Canada's crude oil production is derived from three principal sources: (a) conventional deposits (light and heavy) from the Western Sedimentary Basin; (b) oil sands (synthetic crude oil or SCO and bitumen); and (c) frontier deposits (offshore). A substantial amount of Canada's crude oil production is exported. Supplies from these sources are expected to more than offset the slight decline projected for conventional oil production. Analysis suggests that, for crude oil, Canada should have sufficient capacity to meet growing domestic and foreign demand. Canada will remain a net exporter over a quite long period. Figure 3.1 and Table 3.1 show more details of oil production and supply in Canada.

The climatic factors of concern for petroleum activities in the prairies include temperature, precipitation, wind speed and direction, permafrost depth, extent and degree of ice richness, snow cover depth, extent and length of season, reduced visibility, and river flow regime. The sensitivity of petroleum-related activities to these changes are given in Table 3.2 (Maxwell, 1996).

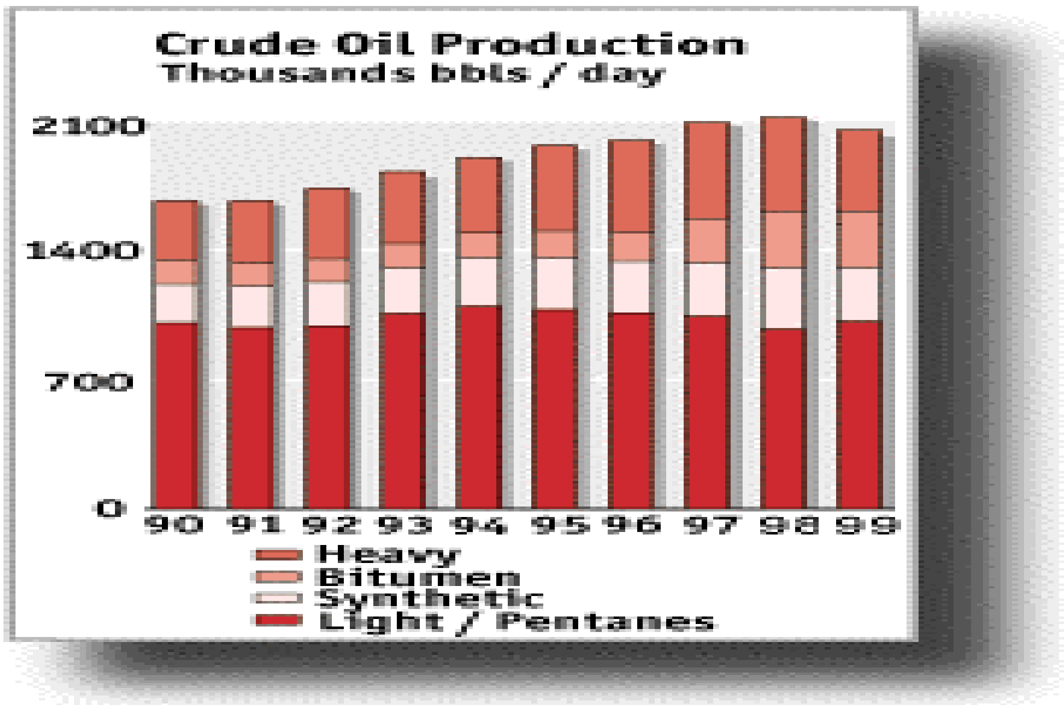


Figure 3.1 Crude oil production in Canada

Table 3.1. Petroleum supply and demand in Canada

	1994	1995	1996	1997	1998
	thousand cubic meters per day				
Supply	**481.8**	**497.6**	**522.9**	**556.2**	**566.5**
Domestic production	361.7	380.1	390.8	406.5	414.5
Crude and equivalent	301.5	312.4	319.0	335.0	342.0
Refined products	260.4	260.3	271.8	281.0	283.6
Motor gasoline	104.1	105.8	109.0	110.5	111.8
- Aviation turbo fuel	11.8	12.7	14.2	14.8	15.2
- Diesel fuel	53.1	52.1	56.7	60.6	64.0
Light fuel oil	27.7	27.4	31.2	27.1	21.2
Heavy fuel oil	19.6	18.0	19.5	20.7	22.1
Ethane, propane and butane	60.2	67.7	71.8	71.4	73.4
Imports	120.2	117.5	132.2	149.7	152.0
Crude and equivalent	98.9	93.9	108.6	121.1	122.4
Refined products	20.6	22.6	22.9	27.7	28.5
Ethane, propane and butane	0.7	1.1	0.7	0.9	1.1
x - data is unavailable, not applicable or confidential					
Source: Statistics Canada, CANSIM, Matrix 2483.					

Table 3.2 Sensitivity of petroleum operations to climate change

Climatic Variables	Sensitivity of Petroleum Operations
Air Temperature	• Steel selection for drill platforms and pipelines • Engine efficiency of construction and maintenance vehicles • Design and operation of compressor operations
Wind	• Design of structure for extreme wind speed • Frequency of reduced-visibility events
Precipitation	• Effect on construction timetables • Contribution to river flow regime
Snow Cover	• Design for land-based construction activities for exploration support, production facilities and pipelines • Continuing access to land facilities for maintenance (e.g. winter snow roads)
Permafrost	• Design and construction of inland and coastal facilities • Continuing access to land facilities
Visibility	• Air and rotary-wing support to construction, operations and maintenance
River Regime	• Pipeline routing and construction • Continuing access to land facilities

3.1. PETROLEUM EXPLORATION AND PRODUCTION PROCESSES

3.1.1. EXPLORATION

Today geologists can make use of various techniques to survey broadly a large expanse of territory and to quickly locate areas for more detailed examination to explore the oil. Geophysicists find that the instruments and techniques available are infinitely more precise and reliable than those used by their predecessors. No longer does an impenetrable forest or water present an obstacle to them for they can take their instruments into the air and record observations while in flight.

(1) Oil search

The preliminary work in locating a possible oil field is to examine such surface evidence as may be available. This is then followed by a detailed geological and geophysical survey in order to select suitable sites for the drilling of test wells. It must be remembered that surface investigations, and even geophysical surveys, can only give indications of the presence of underground conditions and structures suitable to the accumulation of oil in quantity. The drill is the final arbiter concerning the presence or absence of important amounts of oil.

Surface indications of oil

Surface indications of the presence of oil underground may consist of seepages of oil or natural gas or the presence of deposits of solid bitumen. Thus, the famous eternal fires at Baku, Russia, are emanations of natural gas, while the great Pitch Lake in Trinidad is a well-known example of a bitumen deposit. Seepages are usually due to a leakage along a fault plane or to some weakness in the structure, which allows oil or gas to reach the surface, or even to the exposure of the reservoir.

Although a seepage is evidence that oil or gas has existed in the area it is by no means a foregone conclusion that hydrocarbons are still in existence in commercial quantities. However, seepages do offer some encouragement to the explorer, although in numerous cases of active seepages no productive oilfield has been found nearby.

(2) Geological investigation

In this first survey it is often the practice to make a preliminary flight over the whole area. This provides a rapid means of obtaining a good overall picture of the terrain. The preliminary survey will have furnished enough evidence to permit the selection of those areas, which are to be subjected to a detailed survey.

The first step nowadays to the detailed survey will usually be the taking of aerial photographs of the selected areas. Such aerial photographs, made up in pairs and examined by means of a stereoscope, show the country as a small-scale relief model, or they can be laid out as a complete picture of the whole area.

With the results of the preliminary reconnaissance and of the photo geological survey, the geologist will now be able to select those areas, which merit a close study of their geology. The objective will be to prepare accurate maps locating these geological structures which are considered suitable for the trapping and accumulation of hydrocarbons.

(3) Geophysical investigation

The use of geophysical methods in oil search was first made some thirty or more years ago. Although there has been little change in basic principles since that time, there have been very considerable improvements in presenting and interpreting the data obtained. Also the instruments and techniques of their use have been develo*p*ed to meet the demand for large areas to be adequately surveyed in the shortest possible time.

There are three main methods: magnetic, gravimetric, and seismic. Electrical and other methods are also used to a limited extent.

Magnetic method

Measurement of changes in the intensity and direction of the earth's magnetic field brought about by the presence of magnetic rocks can give an indication of subsurface structure. The method is useful in determining depths to the magnetic igneous basin and thus to assist in the mapping of sedimentary basins. Its principal use is for reconnaissance surveys. Today, magnetic surveys are normally made by airborne technique. The instrument can also be towed behind a ship for observations over water-covered areas.

Developments in the magnetometer field include the use of the proton-precession magnetometer in which the detecting element is water or other fluid with a high percentage of hydrogen atoms in a container surrounded by an induction coil. Direct current passed through the coil sets up a polarizing field with which the hydrogen nuclei (protons) align themselves. When the current is switched off the nuclei re-orient themselves with their magnetic axes parallel to the earth's field. The frequency of precession is a direct function of the total magnetic field.

Gravimetric method

Gravimetric method depends on the precise measurement of slight variations in gravity, or more correctly in g the acceleration due to gravity, on the surface caused by the differing densities of the rocks underlying the area. As the density of the rocks varies, so does the gravitational attraction at the surface. Thus, the pull at the surface of a heavy limestone bed in an anticlinal structure is greater over the crest than at a point over the flanks where the limestone is buried deeper.

Among the advantages of the gravimeter is its portability, and instruments weighing as little as 5 lb are available. In this instrument the gravity element is enclosed in an evacuated chamber and it is efficiently temperature compensated.

Seismic method

Developed mainly by the oil industry from the work carried out by seismologists in their studies of earthquakes, this method, which is the most effective one in use at the present time for examining the earth's structure by use of geophysics, is based upon the principle that an explosion in a rigid medium compresses and shears the medium with the result that longitudinal and shear waves are propagated. The two main methods now used are the reflexion technique and the refraction technique.

Electrical methods

At present, the only electrical method available for regional surveys is the telluric. The method is used mainly in combination with a gravity survey in order to reduce misinterpretation of gravimetric data. It is relatively expensive. A similar method is used during the drilling of wells for the identification of formations passed through. Another electrical method is the magneto-telluric. Like the telluric method, the magneto-telluric technique is only occasionally used.

(4) Test drilling

Once the geologists and geophysicists have assessed the results of their observations made on the surface, the next step in determining the presence or otherwise of a commercial oilfield is the drilling of a test borehole or a series of such boreholes. It may be desirable to drill a number of small-diameter holes to check details of geological structure. Such wells may be more than 2000 feet in depth but will generally be drilled by means of a light portable

With all the available information recorded on a map of the area, the location is selected for the first deep test well or, as it is termed in the industry, a 'wildcat' to be drilled. The site may necessitate the building of access roads over which can be transported drilling equipment, accommodation for the drilling crew, and all supplies. In extreme cases, where road building may be too difficult and costly, recourse has been made to the use of helicopters as flying cranes for the transport of all material.

If the 'wildcat' finds oil in appreciable quantities, it is the usual custom to drill a number of 'appraisal' wells in order to delineate as far as is practicable the limits of the producing structure. The information obtained from the appraisal wells is then used to decide the initial production plan for the newly-discovered oilfield.

3.1.2. DRILLING

The well drilled by Colonel L. Drake at Titusville, Pennsylvania, in 1859 and in which oil was found at a depth of 69 feet, is generally assumed to be the first one to have been drilled specifically for the purpose of obtaining crude petroleum. Drake adapted the percussion method for his purpose and in addition installed a steam engine to provide power. After this, a new technique made its appearance. This was the rotary method, in which the cutting tool is rotated in the hole in contrast to the pounding action of the percussion method. The rotary method has itself been subjected to numerous improvements over the years and, except in broad outline, the equipment used today has little resemblance to that first employed.

In some circumstances a rig combining both rotary and percussion methods is employed, thus enabling either system to be used at will according to the nature of the strata being penetrated.

(1) Rotary drilling equipment

The modern rotary drilling outfit includes: (a) the power unit, (b) the drilling tools, (c) the drilling machine, incorporating the draw works and the rotary table etc., and (d) the mud fluid circulation system.

(a) *Power unit*

While the main function of the power plant is to provide power for the rotation of the drilling tools, the hoisting of the tools, and the handling of casing, it is frequently called upon to provide power for ancillary equipment and usually for the operation of the mud pumps. It must be extremely flexible, as at any moment it may be required to provide power for more than one of its functions. The prime mover may be a gas, gasoline, diesel, or steam engine, or a diesel-electric plant.

On the larger outfits the power requirement will be met by the installation of several engines coupled so that one or more can be brought into operation as demands arise. It is customary with large diesel engines to fit torque converters or fluid couplings.

(b) Drilling tools

The 'string' of drilling tools consists of three main items, the drilling bit, drill collars, and drill pipe. Rotary drilling bits are of various types, the selection of which depends on the type of rock being penetrated. Thus, in soft by placing the heavy and rigid drill collars immediately about the bit they reduce the tendency of the drill pipe to bend and to divert the bit off a vertical course. The drill collars are heavy shafts of steel, each is about 30 feet in length and weighs anything from 1/2 to 2 tons according to its diameter. Depending upon the weight required, from two to twenty or more drill collars may be used at one time.

Immediately about the drill collars is the hollow drill pipe, which continues right up to the surface. It is usually made in lengths, or 'joints', of 20, 30, or 40 feet. Its diameter varies from 21 to 7 inches and it may weigh as much as 25 pounds per foot. All parts of the drilling string are provided with special tool joints, which may be welded on to the drill, collar or drill pipe itself, or may be separate, in which case the collar or pipe is threaded at each end.

(c) The drilling machine

For the purpose of this description, the drilling machine is taken to include the rotary table, the draw works, the derrick, and the equipment needed to operate the drilling tools. The tools in the well are rotated by means of the rotary table, a heavy member rotating on ball or roller bearings and set in the center of the derrick floor. The table has a central circular recess in, which can be set the kelly bushings, the latter having a square or hexagonal hole centrally. This hole accommodates the kelly, a section of drill pipe square or hexagonal in outside section and forming the top joint of the drilling string. As the table rotates it turns the kelly and the complete drilling string. The kelly is free to travel vertically in its bushing and thus can be raised or lowered during the drilling operation.

The draw works are in effect the nerve center of the drilling rig, for it is from here that all operations are controlled by the driller. Its principal parts are the hoisting drum, brakes, clutches, cat- heads, and control panel. The mud pumps may also be part of the complete draw works unit.

An important item of the draw works is the hoisting drum, a piece of equipment responsible for handling the drilling string in and out of the hole and also for carrying heavy strings of casing. Brakes are also very important as they are responsible for controlling extremely heavy loads, which may have to be checked without delay. Clutches must also be capable of taking big strains and are generally of the friction type operated pneumatically.

Cat-heads are small drums or pulleys mounted on the side of the hoists and used for many routine operations where comparatively small power is required. Such operations include the making and breaking of joints on pipe or casing.

Support for the tools and hoisting gear is the derrick. The standard derrick is a steel structure, with a base of about 30 feet square and a height of about 140 feet or more. There is also a mast type of transportable derrick, which may be a simple structure or a four-leg structure of considerable strength.

When it is necessary to make or break joints in the drilling string, a pair of tongs, which may be power operated, are employed. To facilitate the handling of these heavy implements their weight may be taken by a wire line which passes over a pulley in the derrick and back to a counterweight under the floor. While drill pipe or other joints are being made or broken, the pipe in the hole is supported by slips or wedges which fit round it in the rotary table and prevent it falling back into the hole.

When drilling is in progress, the swivel provides the connection between kelly and mud pump for the mud fluid to be circulated to the bit. The swivel is so designed as to allow the drilling string to rotate freely on roller bearings, and oil or other seals prevent mud or extraneous matter reaching the bearings. The gooseneck of the swivel is attached by flexible hose to the mud system.

For the control of operations the driller has a series of instruments, consisting usually of a weight indicator, a tachometer, a pressure gauge, a torque gauge, and engine indicators and controls. Probably the most important of these is the weight indicator which shows at a glance the total weight resting on the bit at the bottom of the hole a piece of knowledge essential to good drilling and straight hole.

(d) Drilling mud

The fluid used during the drilling of a well by the rotary system is often referred to as the 'mud'. It is a highly complex liquid having many characteristics imparted to it by the addition of natural or chemical products. These characteristics can be adjusted to meet any variation in the conditions under which the fluid has to perform its duties or any variation in the nature of those duties.

A general requirement of a drilling mud is that, although it may be twice as heavy as water, it must still be pumpable and, if allowed to stand, it must gel so that the cuttings will not settle out. The gel must break easily when the mud is agitated. It must also be non-abrasive in order not to affect the bearings of the bit, heavy enough to exert sufficient pressure to overcome formation pressure, and capable of forming a thin, tough, and relatively impervious mud cake on the uncased walls of a well. To overcome excessive gas pressure, a weighting additive is necessary and for this it is usual to employ barytes.

Drilling mud is tested several times daily during drilling to ensure that it meets the requirements of weight, viscosity, gel rate, gel strength, water loss, wall cake thickness, sand content, and pH. Special apparatus has been designed to test all these characteristics quickly, and an experienced mud engineer can carry out a full analysis in a 1 hour or so and decide on any necessary corrective treatment. The control of drilling mud is a highly specialized operation and the mud engineer has a heavy responsibility in ensuring that the mud is in good condition to enable efficient drilling, and at the same time to protect the rig and its crew from the dangers of a 'blow-out'. In addition to the freshwater based muds mentioned, local conditions sometimes require the use of special muds such as oil-base, oil emulsion, salt water, or lime-base muds. It is this wide variety of constituents which leads to the tendency to the term 'drilling fluid' rather than 'mud'.

For drilling in hard formations the drilling fluid employed may be air, natural gas, or an inert gas such as engine exhaust, although the latter is expensive in capital and operational costs. A modification in which the drilling fluid is mixed with circulating fluid is known as aerated mud drilling. To be successful, a well in which this method is to be used must be substantially free of liquids and the formation must not be subject to caving or falling in. Although air or gas drilling is more expensive on a time-unit basis, the savings brought about by reduction on lost time and by more rapid drilling are said to be a justification for its use.

(e) Mud circulation

The drilling fluid is prepared in the mud pit or mud tanks, from where it is taken up by the mud or slush pump and conveyed by pipe to the swivel. After passing through the well it goes to the shale shaker, a device with a vibrating screen which retains the coarse rock cuttings while the mud falls through into the mud pit where sand and fine sediments settle out. The mud is then reconditioned for further service.

(2) Rotary drilling procedure

The first step in the actual drilling operation is to drill a comparatively large diameter hole, 20 or more inches in diameter, and a few feet in depth, and to cement into this a length of casing. This casing is known as the false conductor or conductor pipe and usually has a smaller pipe branched in horizontally at the top. This latter will be used to convey returning mud to the shale shaker.

When the conductor is set, drilling continues with a hole of sufficient diameter to take the surface casing or 'water string'. The diameter of this may be as much as 16 inches, depending on the full casing program visualized for the well. It may be several hundred feet in length and, with its bottom in impervious strata, it is cemented in place completely from top to bottom. As the surface casing has to carry the blow-out preventer, master valves, production equipment, and also to support the other casing strings, it is important that it is firmly cemented and that no liquid can find its way to the surface through the annular space between it and the side of the hole. It also functions to prevent surface water and loose earth falling into the well.

Drilling then proceeds normally and from time to time it is necessary to lengthen the drilling string by the addition of another length of drill pipe. To do this, the mud pumps are stopped and the string pulled up until the kelly is clear of the table.

(3) Casing

As the well becomes deeper, it becomes necessary to provide protection against the walls falling in and more particularly against the ingress of water. For this purpose the hole is lined with steel casing.

Normally there are at least three strings of casing in a well. The first, the surface or water string has its length varying from a few hundred feet to perhaps 1500 feet according to conditions in the well. The second string of casing, the intermediate string, will be of smaller diameter than the surface string through which it passes. It will serve to isolate salt water-containing beds and in very deep wells, it may be necessary to have more than one intermediate string. The third main string, which is known as the oil string, generally extends from the surface to the top of or even through the producing zone.

It is necessary that each string of casing be held firmly in place and so that there is no access to the well from the annular space between the casing and the walls of the well. For this purpose it is customary to cement each string of casing in position at the bottom, the cement being forced up behind the casing for a considerable distance and possibly right to the top. For this purpose ordinary Portland cement is used, but various additives may be employed to give the cement the special properties required for its particular purpose.

In preparation for cementing, the bottom joint of the casing string is fitted with a float shoe, a steel collar with a rounded nose which can later be drilled out. The shoe serves not only to guide the casing past any irregularities in the well walls but also has a non-return valve which prevents cement running back into the hole. When the casing is in position the required amount of cement is pumped in and followed by a drillable plug. Ordinary drilling mud follows the plug and forces the column of cement down the borehole and up into the annulus behind the casing. When the cement is set, the plug and bottom of the float shoe are drilled out and normal drilling is resumed.

Whilst this is the minimum equipment used for cementing casing, further equipment is used when cementing long strings of casing. This includes a float collar. At intervals up the string are placed centralizers, which are flat springs arranged to keep the casing in the center of the hole to ensure an even thickness of cement all round.

(4) Other rotary drilling methods

Turbo-drill

The basis of the turbo-drill is the provision of a hydraulic turbine at the bottom of the drill string which remains stationary in the well. The turbine is operated by means of the drilling fluid, and it is claimed that the power transmission is increased in comparison with that obtained when a long string of rotated drill pipe is used. Higher rotational speeds of the bit are also obtainable.

Electro-drill

In this method the bit is rotated by an electric motor which may be located at the bottom of the drilling string or, alternatively, may be lowered into the well on a cable. In the latter case, the motor also drives a small fluid pump for circulation of the fluid to keep the bit clear of cuttings. The cuttings are collected in a bailer located above the bit and this necessitates frequent removal of the tools from the hole in order to empty the bailer.

Percussion drilling

As the name implies, the principle on which the percussion system operates is that of pounding the rock into small fragments. This is achieved by means of a chisel-shaped bit alternately lifted and dropped, and turned in the well, the pulverized rock being removed periodically. The modern percussion rig consists essentially of a derrick for hoisting purposes and machinery for operating the drilling tools. The derrick also acts as a support for lengths of tools and casing when required.

The drilling tools used in the percussion system comprise first the bit. Above the bit is the stem, a solid rod to provide weight on the bit, and then the jars. These consist essentially of two sliding links which, on the downward stroke, are fully extended. As the bit strikes the bottom of the hole the links close and, on the upward stroke, again open. The impact when the links become fully extended gives a sharp jerk to the bit to loosen it should it be held in a soft formation. Above the jars is the sinker, a rod similar to the stem and intended to provide weight above the jars. Finally, there is the rope socket to hold the cable by which the drilling string is connected to the surface machinery.

At the surface the drilling cable is clamped to the bottom of the temper screw, a screw assembly which enables the driller to lower the tools as drilling proceeds. The temper screw is attached to the inner end of the walking beam, and the cable goes up and over the crown block and down to the bull wheel.

As the normal bit drills a hole of slightly less diameter than the casing through which it passes, it is necessary to enlarge the hole below the casing shoe when a new length has to be added. For this an under-reaming bit is used, the cutters of which spring out when the bit leaves the bottom of the casing and retract when the bit is drawn back into the casing.

(5) Well surveying

For many reasons, and particularly for accurate correlation of geological information, it is necessary to know the angle from the vertical of any deviation of the well during drilling, and also the direction of that deviation. Instruments used for this purpose may record only the angle or alternatively may determine both angle and direction. The general principle on which instruments for determining the angle operate is a pendulum freely suspended will maintain its verticality.

For the determination of the direction of deviation, the compass principle is employed and various patented designs of instrument to record both direction and angle are available. In some cases a camera photographs the position of pendulum and compass in relation to a chart, while in others the chart itself is marked or punched.

(6) Well logging

Throughout the operation of drilling a well it is necessary to take records of the strata being penetrated and of their characteristics, to determine pressures, to ascertain the production potential of an oil-bearing zone, and to gather any information on which immediate action can be based or long-term plans formulated.

For the simple determination of formation being penetrated, the cuttings from the bit can be collected from the returning mud fluid on the shaker, washed, and passed to the geologist. For the more detailed examination the cores referred to previously in this chapter are collected and reveal a considerable amount of valuable data. In an exploratory well it is often the policy to take a continuous core over very considerable depths. More detailed information can be obtained by electrical or similar methods which are used in practically every well drilled. Resistivity and self-potential logs are usually taken simultaneously and always in an uncased hole which is full of drilling mud.

(7) Drill stem testing

In order to test the production potential of an oil-bearing horizon as soon as it is encountered, use is made of the drill stem testing technique, which also records formation and test pressures. The tester, which is attached to the drill pipe, has valves operated from the surface. Both tester and a formation packer are placed in the well and the packer set above the zone to be tested to seal off the space between the walls of the well and the drill pipe.

(8) Well completion

When the oil- or gas-producing horizon has been penetrated by the drill and tested to ascertain the nature of the reservoir rock and its production possibilities, the next step is to complete the well as a producing unit. A common method of completing a well is to set the oil string at the bottom of the producing sand, cement it in place, and then to perforate the casing. This perforation is done by the use of a gun perforator, which is lowered into the well to the desired depth and then fires bullets or shaped charges through the casing and cement to provide holes through which the oil can flow into the oil string. This method is particularly applicable when there are several oil zones at different depths and the oil string can be perforated opposite each horizon. For actual production purposes a string of tubing of *I*a-46 inches in diameter is run from the surface to the bottom of the hole, and in some cases packers are employed to seal off the space between the oil string and the tubing. In modern practice, several strings of tubing may be run in one well, each tapping an individual producing zone. Individual zones may also be isolated by means of packers in the annular space between casings and between casing and tubing.

On the surface the well head will have been installed and will consist of various parts, including the casing head, the tubing head, the christmas-tree, and pressure and flow gauges.

3.1.3. PRODUCTION

(1) Production Methods

Oil as such has no inherent motive power and therefore cannot by itself move from the reservoir through the well up to the surface. It is fortunate that in most oilfields the energy to move the oil is provided by the pressure of gas or salt water or both which are normally present above or below the oil accumulation in the reservoir rock.

Gas drive

Practically all crude oil in an underground reservoir has gas dissolved in it to a varying extent. When a well is completed it provides a vent to the surface and consequently reduces the pressure around it in the reservoir. As a result gas comes out of solution, expanding as it does, and drives the oil towards the wells and helps to lift it to the surface. By the process of gas drive up to a maximum of about 40% of the oil originally present in the reservoir may be recoverable.

Very often there is more gas than can be held in solution in the oil and the surplus rises to the top of the oil, where it is trapped by the closure on the reservoir and provides a gas cap in which pressure may build up to a comparatively high level. Here again, as the reservoir is punctured, the gas expands and forces the oil towards the wells and to the surface. Total recoveries by gas-cap drive may be a comparatively high percentage of the total in the reservoir.

Water drive

In most oilfields the crude oil is accompanied by vast quantities of salt water, this water being below the oil on the edge of the producing reservoir and in contact with it. Thus, as the oil and gas is taken from the reservoir, the water rises behind it and provides the energy to move the oil still more.

Water drive is probably the most efficient natural oil-production process and, provided that other conditions are satisfactory, may result in the ultimate production of possibly up to 75% of the total oil in the reservoir. In a water-drive field it is essential that the whole oilfield should be operated as a unit and special care taken to control the production rates from individual wells.

Artificial lift

When the reservoir pressure is insufficient to lift the oil to the surface artificial lifting methods are resorted to. In most cases a plunger plug is set at the bottom of the tubing and operated by means of what are termed sucker rods which connect the plunger of the pump to the surface unit.

Another type of artificial lift is the gas lift which is often used to increase the rate of production by injecting gas into the oil column in the well to assist in bringing the oil to the surface. The gas is usually pumped into the annulus between casing and tubing and enters the tubing at selected points through special gas-lift valves.

Secondary recovery

When the energy in a reservoir becomes depleted there still remains in the reservoir a considerable quantity of oil. It is then customary to employ secondary recovery techniques in order to recover still more oil, these techniques involving the injection of water, liquid petroleum gases, or gas into the reservoir.

In the water flooding method, water under pressure is injected into the reservoir through special input wells located at selected points on the structure. The effect is to displace the oil towards the producing wells. Water flooding needs to be controlled very carefully, just as does natural water drive, in order that the oil-water contact line shall travel on an even front.

Gas injection may be used under a variety of conditions. In the early stages of development of an oilfield it may be injected at the top of the reservoir into the gas cap to reduce the normal decline in reservoir pressure. This is known as pressure maintenance. Gas is also injected at later stages in the life of a well and various types of gas, such as natural gas, liquefied petroleum gases, high pressure gases, nitrogen, and so on are used.

A considerable amount of experimental work has been carried out on the application of heat to the reservoir to reduce the viscosity of the oil and augment its flow through the strata. This may be accomplished by the introduction of hot water or steam, and underground combustion has been carried out with some measure of success.

(2) Gas and water separation

Crude oil as it is produced from the well usually contains varying quantities of gas in solution. Before the oil is transported to the refinery it is necessary to remove the bulk of this gas and, for this purpose, the oil is passed through a gas separation plant.

When the oil contains only a small amount of gas, i.e., it has a low gas: oil ratio, a single-phase separator is sufficient. In its simplest form this consists of a vertical or horizontal cylinder into which the gas-oil mixture is introduced so as to give it a swirling motion. In the vertical type the oil enters about half-way up the column, the separated gas going out through the top of the column and the degassed oil from the bottom. The horizontal type is usually set on an incline so that the oil gravitates to the low point. If the crude oil has a high gas/oil ratio, and consequently a high pressure, it is necessary to resort to multi-stage separation to remove the dissolved gas. The crude oil is passed through a series of separators kept at successively lower pressures in each stage so that only a limited amount of gas is allowed to come out of solution at each stage. This ensures that the light hydrocarbons are retained in the separated oil to the maximum extent if the pressures were reduced abruptly it is probable that most of the butanes and some of the pentanes would be carried out with the gases. In some instances as many as seven stages of separation may be used. From the final separator the degassed oil is piped to the stock tanks from where it travels to the refinery either by pipeline direct, or by road, rail, or sea in tanks or tankers.

Crude oil may also contain a small proportion of salt water and the removal of this before refining is necessary. This is best done as far as possible before the oil leaves the oilfield. The water-oil mixture is usually emulsified when it issues from the well. Some water will separate by simple settling in storage tanks, but it may be necessary to apply some form of special treatment, such as the application of a strong electrostatic field to coalesce the water particles into large drops which will settle out by gravity.

(3) Liquid hydrocarbons from natural gas

Natural gas accompanying crude oil or separated from it contains varying proportions of paraffin hydrocarbons up to and including pentane, and is known as 'wet' gas. These liquid hydrocarbons can be extracted from the gas by several processes. These are (a) the compression process in which the gas is compressed and then cooled to condense the heavier constituents; (b) the absorption process in which the wet gas is compressed and contacted in counter-current flow with an absorption oil. The oil takes up the heavier hydrocarbons and these are recovered by stripping in a distillation column; (c) the adsorption process in which the gas passes through a bed of charcoal which preferentially retains the heavier hydrocarbons. The latter are recovered by steam treatment and at the same time the charcoal is rendered fit for further use. This process is used only to a limited extent.

(4) Unitized development

In the early days of the petroleum industry it was customary to drill as many wells as possible in the smallest surface area on the theory that the more wells, the greater would be the oil yield. Thus, wells were drilled with the rigs almost touching one another in some cases and, where adjoining leases were in the hands of different operators, a well on one lease would immediately be matched by one on the next lease, an operation known as line fighting'. This entailed excessive drilling and unnecessary costs.

Well spacing

It may be said that the optimum number of wells in an oil reservoir is the minimum number to allow proper control of the reservoir energy to obtain maximum yield when allowance is made for all factors affecting total cost and revenue.

Although the close spacing of wells may give a higher current rate of production, the ultimate recovery may not be significantly increased and in fact may be lessened. The full effect of well spacing on oil recovery has not been proved but well spacing and production rate do affect the economic return. Present thoughts on the matter are towards a spacing of up to 600 acres per well. Possibly it is better to start operations on a wide spacing of wells, with a closer arrangement later as conditions show this to be desirable.

Unitization

The solution of the problem of the most effective manner of operating an oilfield is unitization, the primary purpose of which is to conserve the natural resource by treating the complete oil or gas field as one unit, siting the wells and organizing production techniques in the best way to obtain maximum ultimate recovery at the minimum cost.

To achieve this it is essential that the entire reservoir be under one control. Where there is only one operator, as in most of the large Middle East oilfields, no problems arise. In most cases, however, an oilfield is operated by a number of lease holders and the co-operation of all is necessary if unitization is to be effective and equable. The owners of royalty interests have also to be considered.

To be complete, unitization should cover all operations, providing means of preventing over-drilling, the application of secondary methods, and selective production in parts of the field to take the place of competitive drilling over the whole area. Some wells may also have to be shut in.

It is preferable that unit operation should be instituted as early as possible in the life of an oilfield. The method of bringing it about in an established or partly-established field will vary according to circumstances. To assist in these negotiations, the American Petroleum Institute has developed standard forms of unit agreement and of unit operating agreement.

The reservoir engineer

Reservoir engineering has been defined as the application of scientific principles to the drainage problems arising during the development and production of oil and gas reservoirs. Therefore the reservoir engineer is of primary importance in that he should be the first to recognize the need for unit operation of the reservoir. It is his duty to study all reservoir data, such as bottom hole pressures, volumetric and phase relationships of reservoir fluids, and information revealed by electrical and other types of log. He will also examine rock samples obtained by coring to determine porosity and permeability and will prepare statistical analyses of well records.

His main function may be summed up as the obtaining of maximum recovery at minimum cost. While his immediate responsibility to his own company is to develop efficiently their own part of the reservoir, he must also give consideration to the position of all operators in the same reservoir and in the general interest.

3.2. IMPACTS OF CLIMATE CHANGE ON PETROLEUM EXPLORATION AND PRODUCTION

The effect of climate change on the costs of exploration activities will differ according to the permafrost depth and distribution. Exploration activities generally include seismic exploration and exploratory drilling. At first blush, it might seem that an extension of summer weather conditions as an outcome of climate change would be beneficial to these activities. However, for most activities, the most active season is during the winter months. This is because of the difficulties associated with travelling and working in a permafrost environment while the active layer is thawed. For example, overland transportation is generally cheaper and easier in the winter because of the existence of ice roads for trucks and the ability to use snowmobiles. In the summer, the movement is difficult because vehicles can easily become bogged down or cause permanent damage to the permafrost, therefore more expensive transportation is often needed. Thus, a longer summer would actually shorten the season for exploration. In permafrost-free regions, however, longer summer and decreases in ice thickness could have a positive impact. Reduction in the ice thickness would allow extended use of exploration rigs with limited ice tolerance leading to reduced exploration costs (Anderson et al., 1996).

The actual magnitude of the exploration costs, based on the impacts described above, are not very important for three reasons. The first is that exploration costs make up a relatively small proportion of total investment associated with a petroleum project. For example, exploration costs represent only 3% of total investment in Croasdle and McDougall's onshore scenario (Croasdle and McDougall, 1992). The second reason is that sufficient exploration has already occurred in Canada's prairies to investigate oil reservoirs under most scenarios that are currently envisioned. Significant impacts on exploration costs would occur for projects that begin 40 or 50 years from now, and it is not reasonable to speculate the state of world oil markets at that time (Anderson et al., 1996).

Drilling of production wells and installation of production facilities (such as pumps, gathering lines, gas plants, and storage tanks) account for over 90% of the investment required for an oil project. Thus, any change in these costs due to climate change would have a profound impact on the feasibility of a project (Anderson et al., 1996).

Changes in warm-season lengths and permafrost conditions would affect overland transportation and infrastructure built on permafrost terrain.

In permafrost-free areas, with a longer summer season, wells could be both drilled and tested in a summer. Thus, for exploratory drilling, the cost could be reduced. Balancing this somewhat with the view that increased precipitation and erosion would have negative impacts on the drilling/production processes by pushing up design requirements for structures and associated facilities.

One might expect the actual cost of drilling to go down, because drilling through permafrost is expensive for a number of reasons. However, in order to prevent collapse of the well due to raised temperature, special pre-chilled drilling mud must be used in place of the conventional ones. Also, drilling equipment must be located on special insulated pads to prevent accelerated thaw in the active layer. Thus, significant savings in construction costs would be reduced. While there are major cost differences between drilling in the presence and in the absence of permafrost, permafrost thickness has a relatively minor effect on drilling cost in those areas where it is present (Anderson et al., 1996).

Table 3.2 shows more details of climate-change impacts on petroleum exploration and production in Canada's prairie.

Table 3.2 Climate-change impacts on petroleum exploration and production in Canada's prairie

Climate-Change	Impacts	Implications
• Warmer winters	• Shorter period with frozen ground	• Shorter winter construction window (frozen ground needed for transportation and construction)
• Increased precipitation	• Muddier, softer roads • Overflow of tailing ponds • Decreased slope stability • Increased flooding	• Difficulties in travelling on roads • Higher road construction costs • Collapse of wells • Increased environmental concerns • Increased safety concerns • Damage to equipment
• Decreased precipitation	• Increased fire frequency • Drier and dustier conditions	• Increased environmental and health safety concerns • Reduced access to the sites • Increased equipment wear • Increased health concerns
• Hotter summers	• Reduced ice load • Increased solar radiation	• Reduced drilling cost • Increased health risk to field operators – may cause skin cancer
• Longer summer	• Drilling and testing in one season • Shorter snow cover period	• Reduced exploration cost • Easier and more economical exploration

4. CLIMATE-CHANGE IMPACTS ON PETROLEUM PROCESSING

Refining and upgrading involve removing "impurities", most of which become valuable by-products in their own right, and breaking down the complex hydro-carbon molecules, which characterize heavy oil, into simpler hydrocarbon molecules.

In Canadian industry, total manufacturing shipments per employee catalogued $1,304,631 in 1990 and displayed $1,539,295 in 1998, indicating a considerable jump of 6.1% each year. In comparison, total shipments per employee in the U. S. displayed $4,905,860 in 1998 compared to the 1990 level of $3,018,359, representing a demonstrable climb of 6.2% each year. In this case, U. S. labor productivity is well above that of the Canadian industry. Difference in this productivity measure can occur for two reasons. First, the workers have become more skilled and efficient at producing the goods in question. Second, the industry in one country may have access to more advanced capital equipment. Third, the cost factors in production may have changed (lower wages or materials, for example). Fourth, the structure of the industry may have been transformed. The outputs of the industry of one country may have changed over time in relation to the other. Finally, it may be a combination of two or more of these factors (Figure 4.1).

In Canada total shipments in 1990 exhibited $18.0 billion and in 1998 exhibited $19.9 billion, or 1.4% on an annual basis. Manufacturing intensity in Refined Petroleum and Coal Products Industries increased from 14% in 1990 to 15% in 1995, a compounded average annual growth rate of 1.4%. In contrast, the compounded average annual growth rate of manufacturing intensity across the entire manufacturing sector increased by 5.2 % annually over the 1990 to 1995 period.

4.1. PETROLEUM REFINING PROCESSES

4.1.1. CRUDE OIL PRETREATMENT (DESALTING)

Crude oil often contains water, inorganic salts, suspended solids, and water-soluble trace metals. As a first step in the refining process, to reduce corrosion, plugging, and fouling of equipment and to prevent poisoning the catalysts in processing units, these contaminants must be removed by desalting (dehydration).

The two most typical methods of crude-oil desalting, chemical and electrostatic separation, use hot water as the extraction agent. The feedstock crude oil is heated to between 150° and 350°F to reduce viscosity and surface tension for easier mixing and separation of the water. In both methods other chemicals may be added.

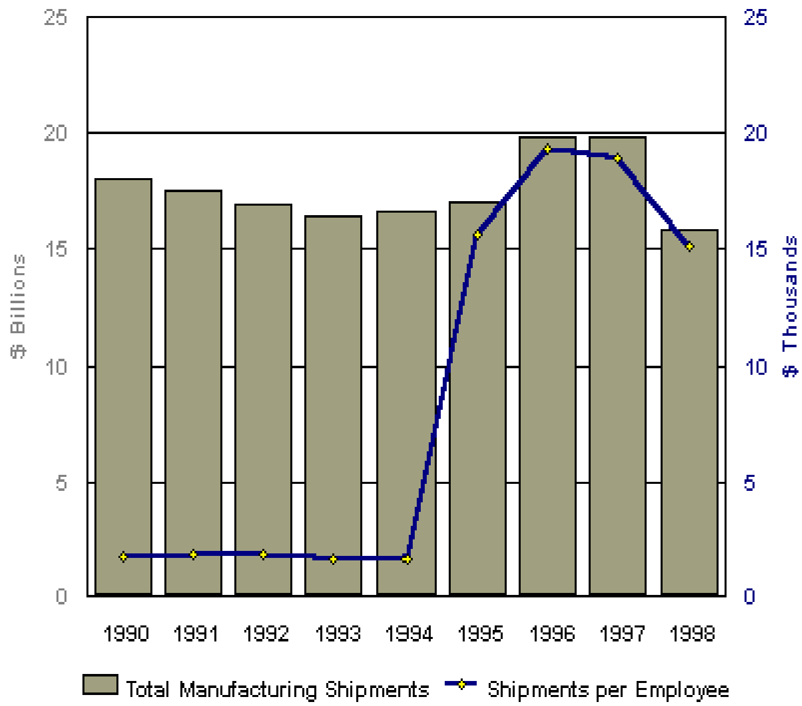


Figure 4.1 Total manufacturing shipments & shipments/employee
(Source: Statistics Canada and Industry Canada)

4.1.2. CRUDE OIL DISTILLATION (FRACTIONATION)

The first step in the refining process is the separation of crude oil into various fractions or straight-run cuts by distillation in atmospheric and vacuum towers. The main fractions or "cuts" obtained have specific boiling-point ranges and can be classified in order of decreasing volatility into gases, light distillates, middle distillates, gas oils, and residuum.

Atmospheric Distillation Tower

The desalted crude feedstock is preheated using recovered process heat, then flows to a direct-fired crude charge heater where it is fed into the vertical distillation column just above the bottom, at pressures slightly above atmospheric and at temperatures ranging from 650° to 700° F. All but the heaviest fractions flash into vapor. As the hot vapor rises in the tower, its temperature is reduced. Heavy fuel oil or asphalt residue is taken from the bottom. At successively higher points on the tower, the various major products including lubricating oil, heating oil, kerosene, gasoline, and uncondensed gases (which condense at lower temperatures) are drawn off.

The fractionating tower contains horizontal steel trays for separating and collecting the liquids. An overflow pipe drains the condensed liquids from each tray back to the tray below, where the higher temperature causes re-evaporation. The evaporation, condensing, and scrubbing operation is repeated many times until the desired degree of product purity is reached. Then side streams from certain trays are taken off to obtain the desired fractions. The distillation process separates the major constituents of crude oil into so-called straight-run products ranging from uncondensed fixed gases to heavy fuel oils.

Vacuum Distillation Tower

Vacuum distillation towers is used to further distill the residuum or topped crude from the atmospheric tower at higher temperatures, reduced pressure is required to prevent thermal cracking. The principles of vacuum distillation resemble those of fractional distillation and, except that larger-diameter columns are used to maintain comparable vapor velocities at the reduced pressures, the equipment is also similar. They are typically used to separate catalytic cracking feedstock from surplus residuum.

4.1.3. SOLVENT EXTRACTION AND DEWAXING

Solvent treating is a widely used method of refining lubricating oils as well as a host of other refinery stocks. Since distillation (fractionation) separates petroleum products into groups only by their boiling-point ranges, impurities may remain. Solvent refining processes including solvent extraction and solvent dewaxing usually remove undesirables at intermediate refining stages or just before sending the product to storage.

The purpose of solvent extraction is to prevent corrosion, protect catalyst in subsequent processes, and improve finished products by removing unsaturated, aromatic hydrocarbons from lubricant and grease stocks. Solvent dewaxing is used to remove wax from either distillate or residual basestocks at any stage in the refining process.

4.1.4. CRACKING

Cracking is the process that breaks or cracks the heavier, higher boiling-point petroleum fractions into more valuable products such as gasoline, fuel oil, and gas oils. The two basic types of cracking are thermal cracking, using heat and pressure, and catalytic cracking.

(1) THERMAL CRACKING

Distillate fuels and heavy oils were heated under pressure in large drums until they cracked into smaller molecules with better antiknock characteristics. This method produced large amounts of solid, unwanted coke. This early process has evolved into the following applications of thermal cracking: visbreaking, steam cracking, and coking.

(2) CATALYTIC CRACKING

Catalytic cracking breaks complex hydrocarbons into simpler molecules in order to increase the quality and quantity of lighter, more desirable products and decrease the amount of residuals. This process rearranges the molecular structure of hydrocarbon compounds to convert heavy hydrocarbon feedstock into lighter fractions such as kerosene, gasoline, LPG, heating oil, and petrochemical feedstock.

Catalytic cracking is similar to thermal cracking except that catalysts facilitate the conversion of the heavier molecules into lighter products. Use of a catalyst in the cracking reaction increases the yield of improved-quality products under much less severe operating conditions than in thermal cracking. The catalysts used in refinery cracking units are typically solid materials.

There are three basic functions in the catalytic racking process:

- Reaction: Feedstock reacts with catalyst and cracks into different hydrocarbons;
- Regeneration: Catalyst is reactivated by burning off coke; and
- Fractionation: Cracked hydrocarbon stream is separated into various products.

The three types of catalytic cracking processes are fluid catalytic cracking (FCC), moving-bed catalytic cracking, and Thermofor catalytic cracking (TCC). The catalytic cracking process is very flexible, and operating parameters can be adjusted to meet changing product demand. In addition to cracking, catalytic activities include dehydrogenation, hydrogenation, and isomerization.

(3) FLUID CATALYTIC CRACKING

The most common process is FCC, in which the oil is cracked in the presence of a finely divided catalyst which is maintained in an aerated or fluidized state by the oil vapors. The fluid cracker consists of a catalyst section and a fractionating section that operate together as an integrated processing unit. The catalyst section contains the reactor and regenerator, which, with the standpipe and riser, forms the catalyst circulation unit. The fluid catalyst is continuously circulated between the reactor and the regenerator using air, oil vapors, and steam as the conveying media.

A typical FCC process involves mixing a preheated hydrocarbon charge with hot, regenerated catalyst as it enters the riser leading to the reactor. The charge is combined with a recycle stream within the riser, vaporized, and raised to reactor temperature (900°-1,000° F) by the hot catalyst. As the mixture travels up the riser, the charge is cracked at 10-30 psi. In the more modern FCC units, all cracking takes place in the riser. The "reactor" no longer functions as a reactor; it merely serves as a holding vessel for the cyclones. This cracking continues until the oil vapors are separated from the catalyst in the reactor cyclones. The resultant product stream (cracked product) is then charged to a fractionating column where it is separated into fractions, and some of the heavy oil is recycled to the riser.

Spent catalyst is regenerated to get rid of coke that collects on the catalyst during the process. Spent catalyst flows through the catalyst stripper to the regenerator, where most of the coke deposits burn off at the bottom where preheated air and spent catalyst are mixed. Fresh catalyst is added and worn-out catalyst removed to optimize the cracking process.

(4) HYDROCRACKING

Hydrocracking is a two-stage process combining catalytic cracking and hydrogenation, wherein heavier feedstock are cracked in the presence of hydrogen to produce more desirable products. The process employs high pressure, high temperature, a catalyst, and hydrogen. Hydrocracking is used for feedstock that are difficult to process by either catalytic cracking or reforming, since these feedstock are characterized usually by a high polycyclic aromatic content and/or high concentrations of the two principal catalyst poisons, sulfur and nitrogen compounds.

The hydrocracking process largely depends on the nature of the feedstock and the relative rates of the two competing reactions, hydrogenation and cracking. Heavy aromatic feedstock is converted into lighter products under a wide range of very high pressures (1,000-2,000 psi) and fairly high temperatures (750°-1,500° F), in the presence of hydrogen and special catalysts. When the feedstock has a high paraffinic content, the primary function of hydrogen is to prevent the formation of polycyclic aromatic compounds. Another important role of hydrogen in the hydrocracking process is to reduce tar formation and prevent buildup of coke on the catalyst. Hydrogenation also serves to convert sulfur and nitrogen compounds present in the feedstock to hydrogen sulfide and ammonia.

Hydrocracking produces relatively large amounts of isobutane for alkylation feedstock. Hydrocracking also performs isomerization for pour-point control and smoke-point control, both of which are important in high-quality jet fuel.

4.1.5. CATALYTIC REFORMING

Catalytic reforming is an important process used to convert low-octane naphthas into high-octane gasoline blending components called reformate. Reforming represents the total effect of numerous reactions such as cracking, polymerization, dehydrogenation, and isomerization taking place simultaneously. Depending on the properties of the naphtha feedstock and catalysts used, reformates can be produced with very high concentrations of toluene, benzene, xylene, and other aromatics useful in gasoline blending and petrochemical processing.

A catalytic reformer comprises a reactor section and a product-recovery section. More or less standard is a feed preparation section in which, by combination of hydrotreatment and distillation, the feedstock is prepared to specification. Most processes use platinum as the active catalyst. Sometimes platinum is combined with a second catalyst (bimetallic catalyst) such as rhenium or another noble metal.

There are many different commercial catalytic reforming processes including platforming, powerforming, ultraforming, and Thermofor catalytic reforming.

4.1.6. CATALYTIC HYDROTREATING

Catalytic hydrotreating is a hydrogenation process used to remove about 90% of contaminants such as nitrogen, sulfur, oxygen, and metals from liquid petroleum fractions. Hydrotreating is done prior to processes such as catalytic reforming , catalytic cracking so that the catalyst is not contaminated by untreated feedstock., and to upgrade middle-distillate petroleum fractions into finished kerosene, diesel fuel, and heating fuel oils.

In a typical catalytic hydrodesulfurization unit, the feedstock is deaerated and mixed with hydrogen, preheated in a fired heater (600°-800° F) and then charged under pressure (up to 1,000 psi) through a fixed-bed catalytic reactor. In the reactor, the sulfur and nitrogen compounds in the feedstock are converted into H_2S and NH_3. The reaction products leave the reactor and after cooling to a low temperature enter a liquid/gas separator. The hydrogen-rich gas from the high-pressure separation is recycled to combine with the feedstock, and the low-pressure gas stream rich in H_2S is sent to a gas treating unit where H_2S is removed. The clean gas is then suitable as fuel for the refinery furnaces. The liquid stream is the product from hydrotreating and is normally sent to a stripping column for removal of H_2S and other undesirable components. In cases where steam is used for stripping, the product is sent to a vacuum drier for removal of water. Hydrodesulfurized products are blended or used as catalytic reforming feedstock.

4.1.7. ISOMERIZATION

Isomerization converts n-butane, n-pentane and n-hexane into their respective isoparaffins of substantially higher octane number. It is important for the conversion of n-butane into isobutane, to provide additional feedstock for alkylation units, and the conversion of normal pentanes and hexanes into higher branched isomers for gasoline blending. Isomerization converts normal paraffins to isoparaffins. There are two distinct isomerization processes, butane (C_4) and pentane/hexane (C_5/C_6).

4.1.8. POLYMERIZATION

Polymerization is the process of converting light olefin gases including ethylene, propylene, and butylene into hydrocarbons of higher molecular weight and higher octane number that can be used as gasoline blending stocks. Polymerization may be accomplished thermally or in the presence of a catalyst at lower temperatures.

4.1.9. ALKYLATION

Alkylation combines low-molecular-weight olefins (primarily a mixture of propylene and butylene) with isobutene in the presence of a catalyst, either sulfuric acid or hydrofluoric acid. The product is called alkylate and is composed of a mixture of high-octane, branched-chain paraffinic hydrocarbons. Alkylate is a premium blending stock because it has exceptional antiknock properties and is clean burning. The octane number of the alkylate depends mainly upon the kind of olefins used and upon operating conditions.

4.1.10. SWEETENING AND TREATING PROCESSES

Treating is a means by which contaminants are removed from petroleum fractions or streams. Petroleum refiners have several different treating processes, the primary purpose is the elimination of unwanted sulfur compounds. A variety of intermediate and finished products, including middle distillates, gasoline, kerosene, jet fuel, and sour gases are dried and sweetened. Sweetening, a major refinery treatment of gasoline, treats sulfur compounds (hydrogen sulfide, thiophene and mercaptan) to improve color, odor, and oxidation stability. Sweetening also reduces concentrations of carbon dioxide.

Treating can be accomplished at an intermediate stage in the refining process. Choices of a treating method depend on the nature of the petroleum fractions, amount and type of impurities in the fractions to be treated, the extent to which the process removes the impurities, and end-product specifications. Treating materials include acids, solvents, alkalis, oxidizing, and adsorption agents.

4.1.11. UNSATURATED GAS PLANTS

Unsaturated (unsat) gas plants recover light hydrocarbons (C_3 and C_4 olefins) from wet gas streams from the FCC, TCC, and delayed coker overhead accumulators or fractionation receivers.

4.1.12. AMINE PLANTS

It remove acid contaminants from sour gas and hydrocarbon streams. In amine plants, gas and liquid hydrocarbon streams containing carbon dioxide and/or hydrogen sulfide are charged to a gas absorption tower or liquid contactor where the acid contaminants are absorbed by counterflowing amine solutions. The stripped gas or liquid is removed overhead, and the amine is sent to a regenerator. In the regenerator, the acidic components are stripped by heat and reboiling action and disposed of, and the amine is recycled.

4.1.13. SATURATE GAS PLANTS

Saturate (sat) gas plants separate refinery gas components including butanes for alkylation, pentanes for gasoline blending, LPG's for fuel, and ethane for petrochemicals. Because sat gas processes depend on the feedstock and product demand, each refinery uses different systems, usually absorption-fractionation or straight fractionation.

4.1.14. ASPHALT PRODUCTION

Asphalt is a portion of the residual fraction that remains after primary distillation operations. It is further processed to impart characteristics required by its final use. Vacuum distillation used to produce road-tar asphalt, the residual is heated to about 750° F and charged to a column where vacuum is applied to prevent cracking.

Asphalt for roofing materials is produced by air blowing. Residual is heated in a pipe still almost to its flash point and charged to a blowing tower where hot air is injected for a predetermined time.

A third process is solvent deasphalting. This extraction process uses propane (or hexane) as a solvent, heavy oil fractions are separated to produce heavy lubricating oil, catalytic cracking feedstock, and asphalt.

4.1.15. HYDROGEN PRODUCTION

High-purity hydrogen (95%-99%) is required for hydrodesulfurization, hydrogenation, hydrocracking, and petrochemical processes. Hydrogen, produced as a by-product of refinery processes, is not enough to meet the total refinery requirements, necessitating the manufacturing of additional hydrogen or obtaining supply from external sources.

In steam-methane reforming, desulfurized gases are mixed with superheated steam (1,100°-1,600° F) and reformed in tubes containing a nickel base catalyst. The reformed gas, which consists of steam, hydrogen, carbon monoxide, and carbon dioxide, is cooled and passed through converters containing an iron catalyst where the carbon monoxide reacts with steam to form carbon dioxide and more hydrogen.

Steam-naphtha reforming is a continuous process for the production of hydrogen from liquid hydrocarbons.

4.1.16. BLENDING

Blending is the physical mixture of a number of different liquid hydrocarbons to produce a finished product with certain desired characteristics. Products can be blended in-line through a manifold system, or batch blended in tanks and vessels.

4.1.17. LUBRICANT, WAX, AND GREASE MANUFACTURING PROCESSES

Lubricating oils and waxes are refined from the residual fractions of atmospheric and vacuum distillation. The objective of the lubricating oil refinery processes is to remove asphalts, sulfonated aromatics, and paraffinic and isoparaffinic waxes from residual fractions. Reduced crude from the vacuum unit is deasphalted and combined with straight-run lubricating oil feedstock, preheated, and solvent-extracted (usually with phenol or furfural) to produce raffinate.

Wax Manufacturing Process. Raffinate from the extraction unit contains a considerable amount of wax that must be removed by solvent extraction and crystallization. It is mixed with a solvent and precooled in heat exchangers. The wax is continuously removed by filters and cold solvent-washed to recover retained oil. The solvent is recovered from the oil by flashing and steam stripping. The wax is then heated with hot solvent, chilled, filtered, and given a final wash to remove all oil.

Lubricating Oil Process. The dewaxed raffinate is blended with other distillate fractions and further treated for viscosity index, color, stability, carbon residue, sulfur, additive response, and oxidation stability in extremely selective extraction processes using solvents (furfural, phenol, etc.).

Grease Compounding. Grease is made by blending metallic soaps (salts of long-chained fatty acids) and additives into a lubricating oil medium at temperatures of 400°-600° F. The characteristics of the grease depend to a great extent on the metallic element (calcium, sodium, aluminum, lithium, etc.) in the soap and the additives used.

4.2. IMPACTS OF CLIMATE CHANGE ON REFINING PROCESSES

Petroleum Refining industry is a chemical industry which would catch impacts of climate change on a number of its processes and activities. With raised temperature and drier atmospheric condition, increased oil vaporization (or leakage) in refinery plants could cause a higher fire frequency. As the refining process is highly vulnerable to fire, the fire could damage the facility in no time. This situation, thus, may lead to increased concerns about cost, safety, health and environment (i.e. air pollution). In addition, the increased amounts of volatile organic compounds (VOC) emissions due to raised contaminant volatility and accidental release could bring up more environmental concerns.

In cooling processes for solvent dewaxing, increased cooling water temperature could lead to eutrophication and many other ecological problems in receive waters.

Increased precipitation in some areas could cause more frequent flooding that could affect drainage systems in refinery plants and associated wastewater treatment plants. Foundation of the facilities could be disrupted due to soil instability. Higher humidity in the atmosphere would enhance corrosion of metal-built equipment. Table 4.1 shows more details of climate-change impacts on petroleum refinery.

Table 4.1 Climate-change impacts on petroleum refinery

Climate Change	Impacts	Implications
• Warmer/drier summers	• Increased smog • Increased cooling water temperature • Increased oil vaporization • Increased VOC emissions	• Refinery operation curtailed • Increased temperature of receiving water body (stream or lake) • Increased fire frequency • Increased safety concerns • Environmental and health concerns
• Decreased precipitation	• More oil/gas leakage • Increased fire risk	• Economic losses • Accidental contaminant releases
• Increased precipitation	• Increased soil instability	• Disruption of facility foundation • On-land contaminant dispersion

5. CLIMATE-CHANGE IMPACTS ON PETROLEUM TRANSPORTATION AND STORAGE

Transmission pipelines are the safest and the most cost-effective method of transporting large volumes of oil and gas that Canada produces each day. Crude oil and natural gas in Canada are transported to market through extensive and sophisticated gathering, transportation, distribution and refining systems that meet domestic demand and provide access to export markets in an environmentally responsible manner. This system includes more than 340,000 miles of pipe (Figure 5.1).

But even pipelines require large investments. Due to the high costs of pipeline construction and operation, economics generally dictate that only one pipeline provides service to one market area. To balance the interests of producers, consumers and pipeline operators, transportation rates or tolls are strictly monitored by federal or provincial agencies. The National Energy Board regulates energy transportation systems crossing interprovincial and international borders. Provincial regulators are responsible for pipelines operating solely within their province. Typically, the cost of moving oil amounts to about 10 per cent of the actual cost of a barrel of oil which in 1997 averaged $27

Crude oil pipeline capacity continues to expand, providing increased access to markets for Canadian producers. Additional expansions to export markets have been proposed or are already in the works. Express Pipeline, the first new major oil pipeline from Canada in 45 years came online in 1996 and Interprovincial Pipe Line has recently announced expansion plans. Northern Border Pipeline Company expanded and extended its system from the Canadian border to Iowa and from there to the major hub at Chicago, Illinois. Alliance Pipeline Limited Partnership is a $3.7 billion proposal to ship 1.3 bcfd gas from northeastern British Columbia and Alberta directly to Chicago. Alliance is expected inservice in late 2000.

5.1. PETROLEUM TRANSPORTATION AND STORAGE

In the early days of the petroleum industry, the crude substance and its products were carried almost exclusively in wooden barrels whether by land or by sea. Today, though drums and cans are still used for the transport of petroleum products in small quantities, the main methods for the transport of petroleum involve bulk quantities. Thus the vehicles used are pipelines, ocean and coastal tankers, barges and river craft, road or rail tank wagons, and even flexible containers which can be loaded on to a truck or towed in water.

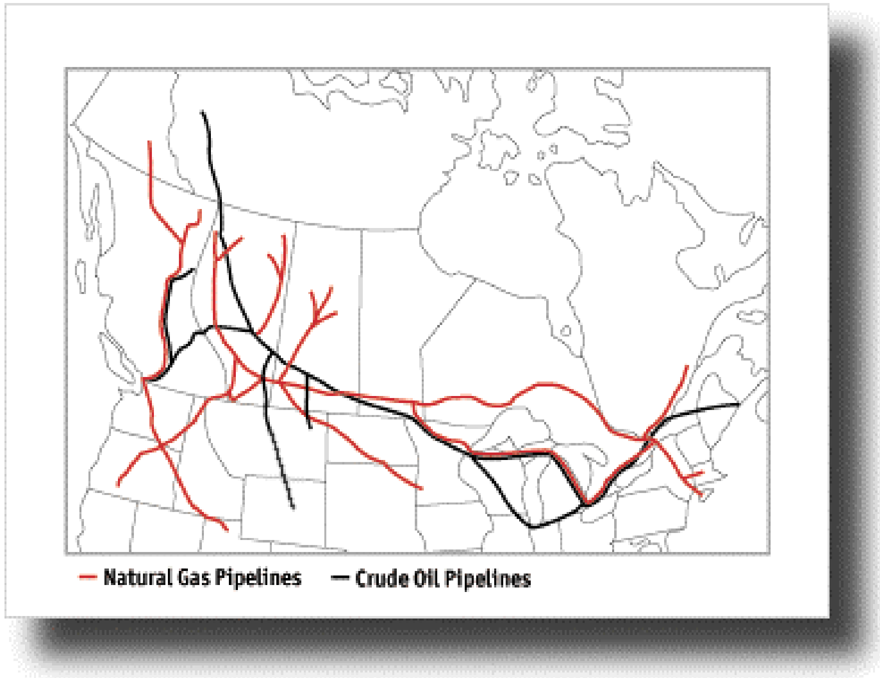


Figure 5.1 Transmission pipelines for crude oil and natural gas

(1) Measurement

As transport is usually concerned with the transfer of the material from oilfield to refinery or refinery to customer, one important matter which, arises is the accurate measurement of quantities. The most used unit of measurement of quantities of crude petroleum and its liquid products is the barrel.

To convert weights to volumes and vice versa account has to be taken of the expansion or contraction due to temperature changes of the substance. Determination of weights or volumes of oil entails accurate measurement of volume, temperature, and specific gravity or density. The complete measurement process is known as gauging and involves tank calibration, sampling, temperature measurement, and gravity determination.

(2) Transport by pipeline

The first successful pipeline for the transport of crude oil was laid in Pennsylvania in 1865. Today, many thousands of miles of steel pipe are in use for gathering crude oil and for the distribution of products the world over, with an even greater length in use for the conveyance of natural gas. Throughout the years the major developments of pipelines have been in respect of length and diameter. In order to conserve space in the transport of pipe to its site for laying, and particularly in regard to sea transport where freight rates are based on volume rather than actual weight, it is usual to nest pipe for transport by placing a smaller diameter pipe inside one of larger diameter.

Pipeline construction

A preliminary step to the construction of a pipeline is a careful survey of the proposed route, bearing in mind the need to avoid as far as possible natural or other obstacles which would necessitate the provision of additional pumping power. Ready access not only during the construction but also at a later time for any necessary maintenance must also be taken into account. The negotiation of wayleaves and concessions has also to be concluded, or at least to reach an advanced stage, before plans can be finalized.

The first operation in the laying of pipeline is the distribution or stringing of pipe along the route. Modern steel line pipe is fabricated in length of 30-40 feet and may be a drawn seamless pipe or of rolled and welded construction. There have also been developments in the manufacture of pipe in situ from flat strip spirally welded in a special machine. The use of such a method could bring considerable economies in transport costs for pipe.

In some locations it is possible for the pipe to be collected initially at central points on the route and then welded into longer lengths. These long lengths are then towed by tractor to their laying position. Much time could be saved by this procedure which would be possible only in comparatively flat areas.

When all is ready successive lengths or joints of pipe are brought together and aligned ready for the welders to join them into the line. to provide for bends in the route, large bending machines are employed to bend the pipe to the required contour.

To protect the pipe from the corrosive action of the soil and from contact with water, it is customary to wrap it with coatings of waterproof material. These wrappings generally consist of coatings of bitumen or coal compositions reinforced with fiberglass and felt. A usual procedure is first to clean and prime the pipe, coat it with bitumen or coal tar enamel with the reinforcement, and finish with a wrapping of impregnated felt.

Whenever possible pipelines are buried to a depth of several feet in the ground and huge machines are employed to prepare the ditch. Where rock is encountered, it may be necessary to use explosives to remove the rock. And in such cases it may be advisable to place a layer of soft earth in the bottom of the ditch to provide a padding to protect the pipe and its wrapping from and risk of damage. A similar padding would also be placed in the sides of the ditch around the pipe when in position.

The final stage before the pipe is lowered into the ditch is to check the continuity of the protective wrapping by sue of "holiday detector". This consists of a circular electrode which is controversies the pipe. The other side of the source is connected to the pipe and the presence of a hole, even a pinhole, in the coating is indicated audible and visibly by a spark at that point.

With the pipe lowered into the ditch, the covering earth is filled in generally by the use of a bulldozer or back-filling machine. In rocky country special care must be taken during this operation to avoid damage to the pipe or its coatings. When the line is completed it has to be tested for any leaks and this is carried out by filling the line with water at a pressure up to about 25% over normal working pressure. If no drop in pressure after 24 hours is observed the line is assumed to be free of leaks.

Corrosion control

The protective coatings previously mentioned are in themselves not completely capable of providing permanent protection in all cases, and it is often found necessary to make use of cathodic protection. The basic principle of cathodic protection is that when two different metals are immersed in an electrolyte such as soil, the one with the higher potential will corrode. In practice the metal of higher potential, the anode, is provided by such metals as magnesium, aluminum, or zinc being electrically connected to the pipe and rendered electro-positive by an external source of direct current. The application of cathodic protection calls for considerable knowledge of its action.

Pumping stations

In most pipelines the flow of the oil needs boosting on its journey, and for this purpose pumping stations are erected at intervals along the line. The spacing of these stations depends on the nature of the terrain, the size of the pipe, and the viscosity of the oil being pumped.

During recent years there has been considerable development in the automatic operation of pumping stations by remote control from a central point. Sequence operation of pumps, valves, etc., and be initiated by radio control or by response to pressure in the line itself. The methods in use vary considerable in technique.

Submarine pipelines

Modern methods of laying pipelines under the water include the "continuous pull" method in which the pipe is on the sea bottom during the whole of the operation. For the actual launching operation the first length of pipe is rolled on to the launching unit , a series of trolleys fixed at regular intervals and over which the pipe passes as it is pulled into the water. The leading end of the pipe is attached to a buoyant pulling head, the tail end being connected trough block and tackle to hold-back winch to provide a restraining force against the forward pull of the pipe. The pulling block is attached by wire line to special heavy-duty winch located on a barge which is securely anchored at an appropriate distance from the shore. When the length of pipe has been towed into the water, a new length is welded on and the joint covered with concrete, while the barge is moved into position ready to take up the pull again.

Another method of laying submarine lines is that in which the pipe lengths are carried on the laying barge. As the barge travels over the route of the line, the completed pipe trails over the end of the barge, new lengths being progressively welded on and wrapped as laying proceeds. The side of the barge is provided with an inclined ramp over which the pipe travels into the water. The vessel is equipped with cranes and all gear needed for completing the line. It is towed by powerful tug.

(3) Transport by tanker

Pumping

The cargo of a tanker is normally discharged by means of the vessel's own pumps. These may be of the horizontal duplex type, with steam supplied from main or auxiliary boilers, or of the centrifugal type driven by steam turbine or electric motor from the main engine room.

Suction pipes near the bottom of each tank take up the oil and convey it to the discharge points on deck. These are manifolded so that different grades of oil can be handled without risk of their becoming mixed. Heavy oils may require heating to reduce their viscosity to facilitate pumping, and for this purpose steam heating coils are fitted in the tanks of vessels likely to be used for such cargoes.

Engines

Steam is needed for many purposes on board a tanker and oil-fired boilers are fitted in all vessels. They may be of the smoke or water tube type and it is usual to pass exhaust gases from main engines through waste heat boilers or some other form of economic heat recovery plant.

Storage installations

The customary storage container for crude petroleum and its liquid products is the cylindrical tank, a type of vessel which has been used for that purpose since the earliest days of the industry. Most of the tanks are vertical, diameters varying from a few feet up to about 180 feet and heights from about 6-60 feet.

Tanks are mainly constructed of mild steel plates and welded. Those tanks which are used for the less volatile products have fixed roofs which are conical in shape and self-supporting to obviate the need for internal columns to support the roof. For crude oil and light products subject to loss by evaporation and to fire hazards, it is customary to use tanks with floating roofs. By always being in close contact with the oil surface, air space is virtually eliminated and evaporation reduced to a minimum.

Other methods of reducing losses by evaporation include the use of breather roofs, i.e., a flexible cover which can take care of the expansion and contraction of the air above the oil. Another method makes use of a polyvinyl chloride sheet which rests on the oil surface and is supported by a number of small floats. A vertical skirting on the periphery forms a seal with the tank wall.

Safely precautions

Whether the storage installation is a refinery tank farm with a large number of tanks, or a small depot, every safety precaution must be taken, particularly in relation to the risk of fire and consequent explosion.

In most of cases large tanks for crude oil are surrounded by "bund" or oil-retaining wall, which encloses sufficient space to hold the contents of the tank in case of fracture and leakage. Where more than one tank is enclosed in one compound, this should be of sufficient capacity to retain the contents of the largest tank plus 10% of the contents of all other tanks.

All storage areas should be provided with adequate means of combating any fire which may break out, including foam installations and water mains. These precautions are specially important in a refinery tank farm, where the consequences of a fire may mean a heavy loss of costly plant.

Inland distribution

In most countries road and rail transport will suffice for the carriage of petroleum products from refinery to depot and on to the customer, or direct from refinery to consumer, although pipelines, coastal tankers, and river craft are often used also for that purpose. The type of transport will depend largely upon accessibility, but generally speaking more consumers can be supplied by road or rail, particularly in the case of packaged products such as lubricants in drums and cans and LPG in pressure containers. Pipelines are used for the transport of products in inland distribution in many countries.

In designing a depot consideration must be given to the needs of the area into which deliveries will be made and the facilities to be provided. This will affect the capacity and type of storage vessels, which should be sufficient to cover average offtake for several weeks at least. Space should also be provided for later expansion or development of additional facilities.

Loading racks for road tankers should be arranged so that the vehicles have a clear run to and from the racks and, if possible, should permit of loading from either side. Although it is customary for several products to be handled at each platform it is preferable to avoid high and low flash point products being handled at the same platform. To guard against static electricity, earthing arrangements should be separate for gantry piping and for the vehicle, and it is essential that loading is not started until earthing is complete.

Gantries and platforms are similar for rail tankers and for road tankers, but for the latter are usually higher to allow access to the dome of the vehicle. The dome is usually reached by a walkway which is hinged to the platform and can be easily placed in position when required. For discharging oils from rail tankers separate hose for each product are preferable.

As in an installation, tanks containing motor or other petroleum spirits are built in bunded areas capable of containing the contents in the case of an accident. For black oil tanks the bund wall is of nominal height only.

In the majority of depots pipelines are above or at ground level and manifolds are provided to facilitate cross-connection between any tank and any delivery point in the system. In most cases the manifold connections are made via valves but in some instances flexible hoses are used for inter-pipe connections.

For viscous fluids pumps are usually of the rotary displacement type, while for handling light products centrifugal pumps are generally employed. The number and arrangement of the pumps in a depot can vary in many ways. Special safety precautions against fire are essential features of all depots and should conform to the recommendations made by the Institute of Petroleum. Mobile and static foam application should be available, as well as CO_2 extinguishers and water supplies.

Road tankers

The transport of bulk quantities of petroleum is controlled by the Petroleum Spirit Regulations. One stipulation is that for products with flash points below 73° F when tested by the Abel instrument the maximum load is 4000 gallons, with not more than 800 gallons in any compartment of a vehicle. Tankers carrying other products are not limited by capacity., but gross laden weight must not exceed 24 tons.

Rail tankers

Rail tankcars are not generally divided into compartments and are mainly filled overhead through the dome. Discharge is usually from the bottom.

5.2. IMPACT OF CLIMATE CHANGE ON PETROLEUM TRANSPORTATION AND STORAGE

The distribution (transmission/transport) of oil appears to be the most vulnerable to extreme climate events. The frequency of extreme events is expected to increase with climate change and this may result in greater system disruption and higher costs. Operations that are currently working on the edge, e.g. encountering difficulties during current extreme events, is likely most sensitive to future changes.

The high cost of transportation is a significant barrier to economical production of oil and gas in discontinuous permafrost area. Oil and gas pipelines are likely more expensive as their design would have to recognize increased permafrost instability. Petroleum activities are very closely tied to design needs for meeting permafrost characteristics. Climate change suggests that the prairie area might experience significant impacts – increased instability of permafrost, and increased flooding and erosional concerns. Thus there could be significant design concerns and cost implications for transportation and distribution operations.

PERMAFROST

Permafrost underlies as much as 25% of the global land surface. In the continuous zone of the extreme north, permafrost occurs everywhere except beneath newly emerged land or deep water bodies (deeper than 3 meter) which do not freeze entirely in the winter (Woo et al., 1993). The northerly and southerly boundaries of the discontinuous zone generally follow the 6-8 ^{o}C and 0 ^{o}C isotherms respectively of mean annual surface air temperature in Canada. Within this zone the actual occurrence of permafrost is governed by localized features such as presence of large water bodies; differing soils; vegetative and snow cover regimes; slope and aspect of ground; natural ground fires; and human activities (Maxwell, 1997).

Surface characteristics of permafrost have two features that have direct relations to atmospheric temperature. They are the active layer of permafrost and the presence of ground ice. The active layers is the zone of annual summer thaw over permafrost, which is a half meter at most in the northern Canadian Arctic. However, it increases to over one meter in more southerly areas. Ice in permafrost builds up slowly over an extended period of time, decades to millennia. It can occur in several different forms ranging from pore ice to massive ground ice. The ground ice is usually concentrated in the upper few meters of permafrost, precisely that area of permafrost, which would thaw first if air temperature rise (Maxwell, 1997).

Both disappearance of permafrost and deepening of the active layer are known to have occurred in the past (Woo et al., 1992). A broad correlation is recognized between air temperature and ground temperature in permafrost. Perhaps the most-recognized work on this has involved data from a number of Alaskan sites (Lachenbrunch et al., 1988) where increase in near-surface permafrost temperatures of 2 to 4 ^{o}C have been observed in the last 50 to 100 years. Table 5.1 shows typical responses of permafrost to climate change (Maxwell, 1997).

PIPELINES

The problem of building a pipeline through areas of permafrost is that the temperature of the product passing through it may cause thawing or freezing, which in turn may cause slumping or heaving the pipeline, possibly resulting in repture (Williams, 1986). Also permafrost slopes are susceptible to landslides which could not only damage the line, but also cause damage to transport routes and rivers. One way to address these problems is to condition the product so that its temperature is close to the temperature of the ground around the pipeline. Because of this problem, it is much cheaper to build a pipeline over permafrost free areas. However, it is not necessarily cheaper to build one over discontinuous permafrost. Local changes in the ground conditions in such areas complicate the problem of keeping the product at the correct temperature. Thus, the effect of permafrost reduction on the costs of pipeline construction and operation depends upon the form which it takes. Pipeline costs are likely to be more expensive due to the need to address increased permafrost instability. Permanent transformations from discontinuous permafrost terrain to permafrost-free terrain should decrease costs, but permanent transformations from continuous to discontinuous permafrost probably will not (Anderson et al., 1996).

At the present time, there are no available projections for how climate change would shift the boundaries of permafrost-free, discontinuous permafrost, and continuous permafrost terrain in the Prairies. Even if a major shift were to a occur, it would be over a period spanning decades rather than years. Thus, even if the cost reduction occurs, it will only be in the very long run (Anderson et al., 1996).

The short-term effect of the expectation of changes in the permafrost regime will almost certainly be an increase in the cost of building a pipeline in the next two or three

Table 5.1. Responses of permafrost to climate change

Permafrost Features	Response
Extent	• Response will vary on both large scales (100s of km) and small (10s to 100s of m) • Over half of the discontinuous zone would disappear eventually • Boundary between continuous and discontinuous permafrost will shift northward by hundreds of kilometers although ultimate position and timing are speculative
Depth	• Active layer deepening slowly in the discontinuous zone to perhaps double its current depth • Ground temperature at the depth of 30 m would increase by 1 °C
Ice-rich Soils	• Tops of ice wedges will degrade • Substantial thaw settlement accompanied by disruption of drainage • Increased likelihood of pronounced permafrost topography
Slopes	• Increased frequency of occurrence of active-layer detachments (shallow landslides) and retrogressive thaw settlement visually scarring the landscape

decades. The economic lifetime of a pipeline is twenty-five years. This means that if a new pipeline were to be built under the expectation that significant changes in the permafrost would occur over twenty-five years, it would have to be designed in such a way as to make it suitable in both the permafrost conditions that are observed at the beginning of its lifetime and those that that are expected to exist at the end of its lifetime. Thus, at any particular point in time it must be "over-engineered". Only when and if a permafrost regime, which is believed to be relatively stable, is in place can the pipeline be designed to a specific set of conditions (Anderson et al., 1996).

An additional point is that the increase in the length of the summer season will most likely increase the construction cost of any pipeline. This is because most of the direct construction work must occur during the winter when transportation is easier. The result of shorter construction season will be to extend the number of years needed to complete the pipeline, and therefore increase financing costs.

Shallow landslides can develop in the permafrost area in response to particularly high air temperatures or high precipitation amounts. Such landslides are effectively active-layer failure. They have been of particular interest due to their potential hazard to pipelines. In ice-rich permafrost areas, drought can also trigger landslides; forest fires whose frequency increase during hot and dry summers.

Under increased precipitation scenario, magnified flooding and erosion could not only enhance scour of pipeline exposed underwater at river crossing but could also affect valves of pipeline network sited at river crossing. In addition, higher frequency and severity of washouts could affect pipeline installation.

Under decreased precipitation scenario, the increased forest-fire frequency could become extremely dangerous for pipelines that pass the firing zone. The consequence would be the occurrence of serious explosion and contaminant emission.

Physical and chemical characteristic of oil (for example: viscosity, density and specific gravity) are vulnerable to climate change particularly. Expansion or contraction of the oil is directly associated with temperature variations. Conversion of weights to volumes and vice versa account has to be taken for measurements in the petroleum industry. Thus extreme temperature could raise the important matter of the accurate measurement of quantities called gauging. Therefore, not only accurate determination of oil temperature is necessary for the final calculation of quantities but also re-calibration of standard hydrometers at different temperature and gravity ranges would be essential to ascertain the gravity or density at the time of measurement. With raised temperature, however, decreased viscosity of oil may promote oil movement through valves at pump station as well as through the pipeline.

Table 5.2. Climate-change impacts on petroleum transportation and storage

Climate Change	Impact	Implications of Impact
• Increased precipitation	• Increased flooding	• Increased erosion and flooding could affect pipeline valves sited at river crossing
	• Increased washout	• Increased frequency and severity of washouts could affect pipeline installation
	• Changes in river flow regime	• Increased scour could expose underwater lines (river crossing) • Increased disruption
	• Muddier, softer roads	• Difficulties for transportation by roads • Higher road construction cost
• Warmer temperature	• Changes to the permafrost regime	• Changes in ground conditions could complicate pipeline construction, operation and fitting • Disruption of rail transport could cause oil spill
• Drier summers	• Increased forest-fire frequency	• Environmental damage • Increased safety concerns
• Increased wind speed	• Increased erosion	• Erosion of ground cover could lead to the failure of pipeline; thus could cause spill or leakage
• Warmer winters	• Shorter period with frozen ground	• Shorter winter construction and maintenance window

6. CLIMATE-CHANGE IMPACTS ON ENVIRONMENTAL MANAGEMENT ACTIVITIES IN PETROLEUM INDUSTRY

Development of petroleum industry is currently associated with a number of environmental concerns, such as solid/hazardous waste generation and accumulation, soil/groundwater contamination, and surface-water pollution. These lead to a variety of impacts, risks and liabilities to the society and for the industries themselves. Consequently, development of effective approaches for remediating the pollution problems is important from environmental and socio-economic points of view.

Pollution problems from petroleum industries may be related to a number of factors, with multi-source, multi-layer, multi-stage, and multi-objective characteristics. Pollutants can be leaked, spilled, and/or emitted from exploration, production and processing sites. After being discharged, the pollutants can migrate through on-site soil, and contaminate surrounding water bodies (groundwater and surface-water), resulting in impacts and risks on human and wildlife. Therefore, the environmental activities associated with petroleum industries are generally related to site cleanup or remediation.

Interactive relationships exist among the above processes, and may vary temporally with dynamic and multiobjective features (Testa and Winegardner 1991). For example, variations of soil/groundwater conditions over time may lead to changes in remediation efficiencies and thus environmental and economic conditions; groundwater quality objectives may affect the choice of remediation techniques; use of a soil remediation technique may affect the choice for a subsequent groundwater remediation approach.

Previously, there have been many studies for individual components related to site remediation practices. They include screening/design for remediation systems and facilities, modeling for remediation processes, simulation for pollutant transport in soil and groundwater, and assessment of environmental impacts/risks (Wood et al. 1984; Testa and Winegardner 1991; Hixson et al. 1993; Chakma et al. 1997). However, very few studies for the impacts of climate-change (e.g. increased temperature, changed precipitation patterns, and reduced soil moisture) on the environmental management activities have been conducted. This section will focus on research of this important issue.

6.1. Site Remediation Processes

In general, site remediation processes include biological, chemical, and various integrated technologies. They can be divided into two categories: in-situ treatment and ex-situ treatment.

(1) In-Situ Treatment

Intrinsic Remediation

Intrinsic remediation identifies and relies upon a variety of naturally occurring biological, physical, and/or chemical processes that reduce contaminant mass, mobility, toxicity, volume, or concentration in soil or groundwater. These natural processes can result in a substantially lower closure cost, with minimal disturbance to the site and lowered risk to the public's health and safety.

Biosparging and Air Sparging

Air sparging is an in situ technology that can be used either to remove volatile compounds from the subsurface or to induce biological degradation of compounds in groundwater and saturated soil. During air sparging, air is injected into the saturated zone, usually below the target cleanup zone. Volatile compounds dissolved in the groundwater and sorbed on the soil particles will partition into the advective air phase and be transported to the vadose (unsaturated) zone. The volatilized compounds can then be collected from the vadose zone by a soil vapor extraction system.

Bioventing

Bioventing is a process that employs enhanced oxygenation of the vadose zone to accelerate contaminant biodegradation. This technology is also highly effective when paired with bioremediation in the saturated zone (biosparging).

Soil Vapor Extraction

Vapor extraction is a proven, nondisruptive, and low cost alternative to excavation and off-site disposal of contaminated soils. The rapid treatment of large volumes of soil in situ makes vapor extraction a practical, cost-effective remedial alternative for many sites.

(2) Ex-Situ Treatment

Landfarming

This is a biological treatment technology where waste materials are applied to soil surfaces as solid sludges or aqueous slurries.

Reactor-Based Bioremediation

The reactor-based bioremediation technologies treat soils, vapors, and liquid streams generated as part of in situ remediation processes, providing for complete site remediation.

Soil Pile Treatment

This technology uses "windrows" constructed on lined areas to facilitate biological degradation of contaminants.

6.2. Climate-Change Impacts

Climate change primarily refers to increased temperature. Other effects may include precipitation pattern changes, increased dryness, reduced soil moisture, and increased natural hazards. They are generally influencing agricultural, industrial, and economic activities. Although it has not been fully identified that those effects are positive or negative, potential impacts on environmental activities need to be analyzed based on short- or long-term considerations.

In general, increased temperature may potentially increase air pollution resulting from accelerated evaporation of pollutants from oil exploration, drilling, storage, processing, and transportation processes. This problem may also bring extra treatment and cost to cleanup processes such as landfarming and composting. Besides, increased temperature and changed precipitation pattern may lead to more facility-safety problems (e.g. increased corrosion and erosion).

Climate change will also lead to changes in the site hydrological and hydraulic conditions, leading to many direct and/or indirect impacts on remediation processes. For example, reduced soil moisture will increase the hardness of soil vapor extraction processes, especially in contaminated sites with low soil permeability. Most of the in-situ remedaition processes include sol vapor extraction such as sparging and slurping. The intrinsic remediation, namely natural attenuation, is highly dependent on site natural conditions. Thus, the changes of site hydrological and hydraulic conditions (e.g. reduced soil moisture and increased dryness) will affect this economical remediation alternative.

In terms of ex-situ treatment, increased temperature and changed precipitation pattern may increase the severity of air pollution, such that extra costs are needed for pollution abatement. Also, reduced soil moisture and increased drought will decrease efficiency of biodegradation and composting processes that are associated with landfarming and windrow systems. There is no obvious impacts on reactor-based bioremediation processes; however, the increased temperature and changed weather pattern would bring more difficulties in the related transportation and storage activities.

Climate change would raise the severity and frequency of some natural hazards (e.g. large runoff event, storm, and flooding) that will definitely affect human activities including any environmental practices.

7. PERCEPTION OF PRAIRIE'S PETROLEUM INDUSTRIES ON CLIMATE CHANGE: IMPACTS, VULNERABILITY, AND ADAPTATION

Over the past 10 years, the oil and gas companies have recognized the potential impacts of climate change, in part because of political pressure. Ross Gelbspan, in his book "The Heat is On", says the misinformation campaign has delayed any serious action by governments despite ten years of warnings from scientists and increasing evidence that global warming is already having a dangerous effect on weather patterns and human activities.

Many other evidences of climate change impacts can be obtained from Intergovernmental Panel on Climate Change (IPCC), which is assembled by the United Nations in 1990 involving 2,500 of the world's leading scientists. They produced a landmark scientific report highlighting the dangers of global warming. Five years later in November 1995, the IPCC repeated its warning and stated that: "the balance of evidence suggests a discernible human influence on global climate." Projected rapid climate change "is likely to cause widespread economic, social and environmental dislocation", the IPCC said. It notes "potentially serious changes have been identified, including an increase, in some regions, of the incidence of extremely high temperature events, floods and droughts, with resultant consequences for fires, pest outbreaks and ecosystems".

Some potential impacts on energy sector have been identified. For example, Linder and Inglis (1989) reported that global warming could increase annual electricity generation and generation fuel use in the United States by 4 to 6 percent by 2025. The most significant adverse impacts of climate change on energy sector could be the effects of higher temperature on the use of electricity and on the direct use of fossil fuels for heating. Increases in extreme weather might result in some regional changes in consumption if such weather changes result in population shifts. This effect is also lead to significant impact on electric generation.

While some studies have been undertaken on the adverse effects on general energy sector, very few works on the perception of petroleum industry to climate change impacts have been reported.

In Canada's prairies (Alberta, Saskatchewan, and Winnipeg), petroleum and petrochemical industries are the major components of their economies. Oil and gas reserves in these provinces are among the most economically valuable natural resources in Canada. One of the most important concerns on the development of petroleum and petrochemical industries is the potential adverse effect on them from climate change or specifically global warming.

The objective of this section is to investigate the perceptions of petroleum industries on climate-change impacts, through a systematic survey study. The results could provide bases for influencing the related actions and policies in industries and governments.

7.1. PERCEPTION OF CLIMATE CHANGE IMPACTS ON PETROLEUM INDUSTRIES IN CANADA'S PRAIRIES

Understanding climate-change impacts is particularly important to Canada's prairies due to the significant impacts and risks to the petroleum industries. Effectively communicating climate change impacts is of utmost importance if industries are to be involved in adapting to the effects of global warming. In order to facilitate effective communication, it is necessary to understand how industries perceive the impacts on their activities.

Many factors can affect the industry's perception of climate change impact. Sandman (1989) refers to "outrage factors" when describing how impacts being evaluated. In particular, impacts that are perceived to be involuntary, industrial, unfair, memorable, and dreaded are considered more risky than those that are voluntary, natural, fair, familiar, not memorable, and not dreaded. Since virtually no information was available about impact perceptions in this area, this research is important in terms of its efforts for obtaining the first-hand feedback.

7.1.1 METHODS

(1) Study sample

Petroleum and petrochemical industries in the prairies are involved in many exploration, production, refining, and transportation activities. For example, in Saskatchewan, the oil and gas companies include Shell, Husky, PetroCanada, TranGas, Wascana Energy, etc. The related governmental organizations include Saskatchewan Research Council (SRC), Environment Canada, Saskatchewan Energy and Mine (SEM), and Saskatchewan Environmental Resources Management (SERM). To assure that our sample represent a diverse distribution of the petroleum-related personnel, a number of petroleum-related companies and governmental organizations in Saskatchewan, Alberta, and Manitoba are surveyed.

(2) Study design

A number of methods including interview, questionnaire, literature review, and web site searching have been used in this study. Questionnaires are designed for surveying perceptions of industrial and governmental personnel on climate-change impacts on petroleum industries. The questions are related to knowledge and perception of climate-change impacts on the performance of petroleum-related activities, as well as the related policies and adaptation alternatives. Based on our findings from focus groups, the original questionnaire was improved. Questions about insignificant impacts were removed, and many more specific impacts dedicated to petroleum industries were added.

Questions were asked in the questionnaire survey, such as:

1. Are there any impacts from climate change on petroleum sector in Saskatchewan or your company? What are these impacts?

2. What are the activities or processes in your company taht are vulnerable to climate change such as changes in temperature, precipitation?

3. How about the performance of typical facilities and processes in your company under different climate conditions?

4. Is there any increase on the capital and/or operating costs due to climate change effects?

5. Has your company/agency planned to undertake any research projects or activities in terms of climate-change impact and adaptation? If yes, could you provide some examples (such as modification of industrial processes and/or technologies, improved policies and/or regulations)?

On the basis of the first survey in 2000, a more intensive questionnaire is designed for studying the adaptation strategy of petroleum industries in Canada's Prairie. Especially, the potential adaptation actions are detailed in the second comprehensive survey questionnaire. A set of questionnaire is attached in Appendix A. The questions cover the following three parts:

i) The perceptions of climate changes in Canada's Prairie from research organization, industry, government, and non-governmental organization (NGO).
ii) Their strategy to adapt petroleum industry to the climate changes
iii) What are the specific adaptation actions you would like to recommend.

In detail, climate change consequences considered in the survey are:

1) increased temperature
2) changed precipitation pattern
3) changed humidity and cloud pattern
4) increased natural hazards

The above climate change will potentially have positive or negative impacts on the:

- Cost
- Operation
- Pollution emission status, and

- Infrastructures

of the following 12 activities within petroleum industry:

1	oil exploration processes
2	petroleum exploration processes
3	drilling and production operations
4	exploration and production infrastructures
5	transportation activities within exploration and production processes
6	cost of exploration and production
7	petroleum refining process
8	pollutant emission within oil refinery process
9	cost of oil refinery process
10	petroleum transportation and storage
11	cost of transportation and storage
12	environmental management activities in petroleum industry

The sample questions are shown as follows:

Question: Will increased temperature affect oil exploration processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	Positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Site condition	[ ]	[ ]	[ ]
(c) Testing condition	[ ]	[ ]	[ ]
(d) Equipment operation	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate the condition of related field works under increased temperature [ ]
(b) Change the timetable of field survey [ ]
(c) Increase the efficiency of field works to shorten the survey period [ ]
(d) Develop new technology and survey instruments [ ]
(e) Others [ ] Please specify (optional):

The obtained information provides useful guidance and/or reference for implementation of many tasks in this research, interpretation of the impact/adaptation analysis results, and comparisons among various adaptation scenarios.

(3) Data collection

Data were collected from February through March 2000 for the first questionnaire survey. Among individuals who were approached, the number of refusals was less than 10%. After verbal consent was obtained, the interview was conducted in participants' office. Each interview took approximately 20 ~ 40 minutes, with the help of a questionnaire. From February through June, 2001, data were collected for the second questionnaire survey, the number of refusals was less than 3%. Among individuals who were contacted, they spent several hours to a few days to finish the survey. Some of the feedback is collected through fax, phone call, and email.

(4) Data analysis

The obtained data were analyzed and interpreted using multivariate statistical and Chi-square methods in sections 7.2 and 7.3. Some more contacts with industrial and governmental personnel were made for further clarification. Feedback from a focus group was used for supporting result interpretation.

7.1.2 RESULTS

(1) Characteristics of the sample industries

In Canada's prairies, petroleum industry is one of the primary components in the energy sector. It also contributes to the majority of economy in Canada. Among the petroleum industries, most of them are oil and gas companies. In each year, a large amount of oil and natural gas is exported from Canada to the United States and other countries. The oil and gas companies are mainly associated with exploration, drilling, processing, and transportation activities. The oil and gas pipeline has become an well-organized network in the North America. Additionally, a number of refineries are located in Alberta and Saskatchewan and they are the major part of the Canadian petrochemical industry.

Three categories are selected and they are: (1) oil and gas company, (2) petrochemical company, (3) research organization, (4) government, and (5) non-profit organization. The proportions of them in the first survey can be found in Table 7.1(a), and of them in the first survey can be found in Table 7.1 (b).

A). Results from the first survey

(1) Perception of impact factors

Increased temperature is considered an obvious factor that affects oil and gas companies. The other factors include changes in precipitation, cloud pattern and humidity, and increased natural hazards (e.g. fire, runoff, storm, and flooding). As indicated in Table 7.2, the factor of temperature increase is rated as significant by a larger percentage of respondents than the other effects. The second ranked impact factor is the increased natural hazards based a long-term consideration; obviously, there are no positive effects on industrial activities from increased natural hazards.

For the factors of precipitation, cloud pattern and humidity, the feedback is relatively uncertain. In terms of precipitation, the potential impact is perceived to be "significant" by 20% of respondents, "minor" by 25%, "no impact" by 15%, "both positive and negative" by 22%, "positive" by 8%, and "unsure" by 10%. For humidity and cloud pattern, a higher percentage (33%) of respondents answered "unsure" (33%); in comparison, 12% considered the impact being "significant", 23% "minor", and 9% "positive".

(2) Climate-change impacts on petroleum-related activities

The potential impacts of climate change on petroleum-related activities were investigated, where issues of cost, efficiency, pollution, and operation are considered. The impact factors include increased temperature, varied precipitation pattern, and increased natural hazards.

Table 7.3 shows the perceptions for the impacts of increased temperature on cost, efficiency, pollutant emission, and system operation within petroleum industries. Due to complexities of industrial processes, it is hard to determine direct adverse effects on energy efficiency, such that 45% of the respondents answered "unsure". More than 40%

Table 7.1.1 Sample categories (a)

Oil and gas company	65%
Government	20%
Petrochemical company	15%

Table 7.1.2 Sample categories (b)

Industry	22.2%
Government	19.4%
Research organization	50.0%
Non-profit organization	8.4%

Table 7.2 Perception of climate-change impacts on petroleum industries

	Increased temperature	changed precipitation pattern	changed humidity & cloud pattern	increased natural hazards
Significant	91%	20%	12%	75%
Minor	8%	25%	23%	11%
No impact	0%	15%	10%	5%
Both negative and positive	1%	22%	13%	0%
Positive	0%	8%	9%	0%
Unsure	0%	10%	33%	9%

Table 7.3 Impacts of increased temperature

	Cost	Efficiency	Operation	Pollutant emission
Negative	20%	9%	21%	55%
Positive	22%	11%	20%	7%
Both positive and negative	51%	35%	42%	15%
Unknown	7%	45%	17%	23%

of respondents stated that both negative and positive effects will be posed on the cost and operation. For example, more cooling will be required when temperature is increased; on the other hand, less heating will result in reduced heating costs. The majority of the respondents agree that increased temperature will increase the severity of air pollution.

Table 7.4 gives the perceived impacts of precipitation pattern changes. More than 30% of the respondents agree that there are negative effects from precipitation pattern changes. This is in part due to increased difficulty in system operation as well as impacts on transportation and storage facilities. In addition, potential impacts on temporal and spatial distributions of acid rain and particulate pollution problems may exist.

All of the respondents agreed that increased natural hazards will significantly affect performance of the industrial activities. The surveying results are given in Table 7.5.

(3) Perception on the demand for adaptation

Very few respondents responded that the issue of adaptation has been considered or under study. Most of existing studies are related to the reduction, diversion, and disposal of greenhouse gas emissions, due mainly to political pressure.

However, more than 90% of the correspondents agreed that further investigation and analysis of climate-change impacts on their activities are needed. For governments, adjustment of related policies would help to facilitate more effective adaptation.

B). Results from the second survey

A large amount of valuable results have been produced from the second survey, which is comprehensive and involves more than 45 experts including professors, senior engineers, managers, and technicians from industry, government, research organization, and non-governmental organization. The complete set of results can be easily accessed in the developed Expert System described in section 7.4.

Among the climate change factors, increased temperature is the most significant issue. Its impacts on various aspects of petroleum industry have been identified through the survey of the following questions:

- Will increased temperature affect oil exploration processes?
- Will increased temperature affect drilling and production operations?
- Will increased temperature affect exploration and production infrastructures?
- Will increased temperature affect the cost of exploration and production?
- Will increased temperature affect the petroleum refining process?

- Will increased temperature affect petroleum transportation and storage?
- Will increased temperature affect environmental management activities in petroleum industry?

The detailed analyses of the survey results for this part are depicted as follows:

(A) Will increased temperature affect oil exploration processes?

11.1% of the survey results indicate that increased temperature affects oil exploration processes significantly, 75% of the survey results confirm that the increased temperature affects oil exploration processes, 13.9% of the survey results are not sure whether the increased temperature affects oil exploration processes or not.

Thus, the majority of the survey results indicate increased temperature really affects oil exploration processes.

The sources of the survey results are from the follows:

- In the industry category, 75% of the individuals think that increased temperature will affect oil exploration processes, 25% are not sure.
- In the government category, 71.4% of the results show that increased temperature will affect oil exploration processes, 28.6% are not sure.
- In the research organization category, 22.2% think that increased temperature will affect oil exploration processes significantly. The rest of this group indicates that oil exploration processes will be affected. Namely, they are 100 percent sure that increased temperature will affect oil exploration processes.
- In the non-governmental organization category, 66.7% think that oil exploration processes will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect oil exploration processes, 25.8% think it is better to show concerns and be alerted, 22.6% want to conduct research and gain insight, 29% will conduct research and be prepared to take actions, and 22.6% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

37.1% suggest to investigate the condition of related field works under changing climatic conditions, 22.6% will change the timetable of field survey, 17.7% will try to increase the efficiency of field works to shorten the survey period, and 22.6% will develop new technology and survey instruments.

(B) Will increased temperature affect drilling and production operations?

5.6% of the survey results indicate that increased temperature affects drilling and production operations significantly, 55.6% of the survey results confirm that the increased temperature affects drilling and production operations, 33.3% of survey results indicate a minor impact, 5.6% of the survey results are not sure whether the increased temperature affects drilling and production operations or not.

> *Thus, over 90% of survey results indicate increased temperature really affects drilling and production operations.*

The sources of the survey results are from the follows:

- In the industry category, 37.5% of the individuals think that increased temperature will affect drilling and production operations, 50% indicate minor impact on drilling and production operations, 2.5% are not sure.

- In the government category, 28.6% of the results show that increased temperature will affect drilling and production operations significantly, 57.1% indicate impact on drilling and production process, 14.3% think there is minor impact.

- In the research organization category, 72.2% conclude that increased temperature will affect drilling and production operations, 27.8% think there is minor impact.

- In the non-governmental organization category, 66.7% think that oil exploration processes will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect drilling and production operations, 2.9% think no action is needed, 29.5% think it is better to show concerns and be alerted, 14.8% want to conduct research and gain insight,
35.2% will conduct research and be prepared to take actions, and 17.6% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

28.4% suggest to investigate all possible impacts,16.7% will change the timetable of field survey, 11.8% will select anti-erosion steel for drilling equipment, 9.8% suggest to enhance the maintenance of various instruments, another 11.8% will try to introduce new technique to increase drilling efficiency, 7.8% suggest to use high efficiency compressors and motors in drilling operations, 5.9% suggest to use steam produced from highly efficient co-generation plants to assist with recovery of heavy oil, and 7.8% will install a clean-burn compressor and install a clean-bum compressor and emission controls on a dehydrator unit and use compressed air-activated, rather than gas-activated valves.

(C) Will increased temperature affect exploration and production infrastructures?

61.1% of the survey results indicate that the increased temperature affects exploration and production infrastructures, 19.4% are minor impacts, 5.5% are no impact, 13.9% of the survey results are not sure whether the increased temperature affects exploration and production infrastructures or not.

> *Thus, over 80% of survey results indicate increased temperature really affects exploration and production infrastructures.*

The sources of the survey results are from the follows:

- In the industry category, 50% of the individuals think that increased temperature will affect exploration and production infrastructures, 25% suggest minor impact on exploration and production infrastructures, 25% are not sure.

- In the government category, 42.9% of the results show that increased temperature will affect exploration and production infrastructures, 28.6% of the results indicate minor impact and 28.6% are not sure.

- In the research organization category, 83.3% think that increased temperature will affect exploration and production infrastructures, 5.6% of this group indicates that increased temperature has minor impact on exploration and production infrastructures, 11.1% think there is no impact on exploration and production infrastructures.

- In the non-governmental organization category, 66.7% think that oil exploration processes will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect exploration and production infrastructures, 12.1% think that no actions are needed, 42.5% think it is better to conduct research to gain insight, 12.1% will conduct research and be prepared to take actions, and 33.3% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

26% suggest to investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures, 12.5% will change the timetable of constructions, 9.4% will try to improve the construction efficiency to shorten project period, 19.8% will enhance the maintenance of various constructions, 16.7% will redesign the foundations and structures to adapt to changed condition, 15.6% will redesign pipeline system to handle greater variability of temperature.

(D) Will increased temperature affect the cost of exploration and production?

66% of the survey results indicate that the increased temperature affects the cost of exploration and production, 11.1% of the results suggest minor impact, and 13.9% of the survey results are not sure whether the increased temperature affects the cost of exploration and production or not.

> *Thus, the majority of survey results indicate increased temperature really affects the cost of exploration and production.*

The sources of the survey results are from the follows:

- In the industry category, 37.5% of the individuals think that increased temperature will affect the cost of exploration and production, 25% suggest minor impact, and 37.5% are not sure.

- In the government category, 71.4% of the results show that increased temperature will affect the cost of exploration and production, 28.6% are not sure.

- In the research organization category, 71.4% of this group indicates that the cost of exploration and production will be affected, 28.6% suggest minor impact.

- In the non-governmental organization category, 66.7% think that the cost of exploration and production will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect the cost of exploration and production, 14.3% suggest to do nothing, 39.3% think it is better to show concerns and be alerted, another 14.3% want to conduct research and gain insight, 7.1% will conduct research and be prepared to take actions, and 25% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

46% suggest to investigate all possible impacts, adaptive process, and potential measures, 4% will use more efficient compressors, 18% will use high-pressure gas feed, which is rich in liquids and low in hydrogen sulfide, thus lower energy requirements, 8% will use dual-action pumps at extraction sites to separate the oil and water from the underground, virtually eliminate gas emissions and reduce the amount of energy used to lift the water from underground, and 24% will find and repair leaks in facilities and processing equipment, install vapor recovery equipment.

(E) Will increased temperature affect the petroleum refining process?

13.9% of the survey results suggest that increased temperature will affect the petroleum refining process significantly, 19.4% of the survey results indicate that the increased temperature affects the petroleum refining process, 33.3% of the results suggest minor impact, 13.9% are no impacts, and 19.4% of the survey results are not sure whether the increased temperature affects the petroleum refining process or not.

> *Thus, 47% of survey results indicate increased temperature will affect the petroleum refining process, about 20% of the survey results show no impacts on the petroleum refining process.*

The sources of the survey results are from the follows:

- In the industry category, 25% of the individuals think that increased temperature will affect the petroleum refining process significantly, another 25% of the individuals think that increased temperature will have minor impact on petroleum refining process, 12.5% suggest no impact, and 37.5% are not sure.

- In the government category, 42.8% of the individuals think that increased temperature will affect the petroleum refining process significantly, 28.6% of the individuals think that increased temperature will have minor impact on petroleum refining process, 28.6% are not sure.

- In the research organization category, 16.7% of the individuals think that increased temperature will affect the petroleum refining process significantly, another 16.7% of the individuals think that increased temperature will affect petroleum refining process, 33.3% of the individuals think that increased temperature will have minor impact on petroleum refining process, 22.2% suggest no impact, and 11.1% are not sure.

- In the non-governmental organization category, 33.3% think that the petroleum refining process will be affected and 66.7% are not sure.

Among the individuals who think the increased temperature will affect the petroleum refining process, 8.3% suggest to do nothing, 25% think it is better to show concerns and be alerted, another 8.3% want to conduct research and gain insight, 41.7% will conduct research and be prepared to take actions, and 16.7% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

31.3% will investigate all possible impacts, adaptive process, and potential measures, 9.4% will try to use innovative techniques to prevent oil leakage, spill, and release, 18.8% will install automatic monitor system to reduce the fire risk, 14.1% will choose to control temperature to prevent thermal cracking within facilities, 6.3% will take anti-erosion action to decrease the rates of corrosion of the related facilities, 9.4% will find and repair the leakage, and 10.9% will install oil vapor recovery system.

(F) Will increased temperature affect the pollutant emission within oil refinery process?

13.9% of the survey results suggest that increased temperature will affect the pollutant emission within oil refinery process significantly, 44.4% of the survey results indicate that the increased temperature affects the pollutant emission within oil refinery process, 13.9% of the results suggest minor impact, 8.3% are no impacts, and 19.4% of the survey results are not sure whether the increased temperature affects the pollutant emission within oil refinery process or not.

> *Thus, majority of survey results indicate increased temperature will affect the pollutant emission within oil refinery process, about one-tenth of the survey results show no impacts on pollutant emission within oil refinery process.*

The sources of the survey results are from the follows:

- In the industry category, 12.5% of the individuals think that increased temperature will affect the pollutant emission within oil refinery process, another 12.5% of the individuals think that increased temperature will have minor impact on petroleum refining process, 12.5% suggest no impact, and 62.5% are not sure.

- In the government category, 57.1% of the individuals think that increased temperature will affect the pollutant emission within oil refinery process significantly, 28.6% of the individuals think that increased temperature will have impact on petroleum refining process, 14.3% are not sure.

- In the research organization category, 5.6% of the individuals think that increased temperature will affect the pollutant emission within oil refinery process significantly, 61.1% of the individuals think that increased temperature will affect petroleum refining process, 16.7% of the individuals think that increased temperature will have minor impact on petroleum refining process, 11.1% suggest no impact, and 5.6% are not sure.

- In the non-governmental organization category, 66.7% think that the pollutant emission within oil refinery process will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect the pollutant emission within oil refinery process, 19.2% think it is better to show concerns and be alerted, 26.9% want to conduct research and gain insight, 26.9% will conduct research and be prepared to take actions, and 26.9% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

24.5% suggest to investigate all possible impacts, adaptive process, and potential measures, 16.3% will innovate current techniques to reduce the pollutant emission of each process unit, 10.2% will increase the use of natural gas, replacing petroleum as the facility's source of energy, 11.2% will use the CO2 recovered from refining operations to carbonate soft drinks, 10.2% will develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, feels and fertilizer, 13.3% will install oil vapor recovery system, 10.2% will promote wider acceptance of diesel engines for offering greater fuel efficiency to lower CO2 emissions, 4.1% will develop improved ethanol-enhanced gasoline.

(G) Will increased temperature affect petroleum transportation and storage?

31.25% of the survey results suggest that increased temperature will affect petroleum transportation and storage significantly, 38.9% of the survey results indicate that the increased temperature affects petroleum transportation and storage, 41.7% of the results suggest minor impact, and 5.6% of the survey results are not sure whether the increased temperature affects petroleum transportation and storage or not.

> *Thus, more than half of survey results indicate increased temperature will affect petroleum transportation and storage, some survey results indicate minor impacts on petroleum transportation and storage.*

The sources of the survey results are from the follows:

- In the industry category, 37.5% of the individuals think that increased temperature will affect petroleum transportation and storage, 50% of the individuals think that increased temperature will have minor impact on petroleum refining process, and 12.5% are not sure.

- In the government category, 57.1% of the individuals think that increased temperature will affect petroleum transportation and storage significantly, 42.9% of the individuals think that increased temperature will have impact on petroleum refining process.

- In the research organization category, 27.8% of the individuals think that increased temperature will affect petroleum transportation and storage significantly, 38.9% of the individuals think that increased temperature will affect petroleum refining process, 16.7% of the individuals think that increased temperature will have minor impact on petroleum refining process, 11.1% suggest no impact, and 5.6% are not sure.

- In the non-governmental organization category, 66.7% think that petroleum transportation and storage will be affected and 33.3% are not sure.

Among the individuals who think the increased temperature will affect petroleum transportation and storage, 38.2% think it is better to show concerns and be alerted, 23.5% want to conduct research and gain insight, 17.4% will conduct research and be prepared to take actions, and 20.6% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

17.8% suggest to investigate all possible impacts, adaptive process, and potential measures, 6.1% will use more accurate measurement instruments, 12.3% Redesign pipeline to enhance the foundation to improve the stability of pipeline, 4.9% will change the timetable of pipeline installation, 6.1% will improve the installation efficiency to abbreviate the installation period, 6.1% will select new material to prevent corrosion of pipeline, 4.9% will improve the stability of pump station operation, 11.7% will redesign the foundation of storage tanks, 6.1% will strengthen land use planning regulations in damage-prone areas, 8.6% will install fire alarm and prevention system, 6.1% will use computerized devices to detect weaknesses in pipeline walls and foundation instability, and 9.2% will redesign tanks to reduce the spill and leakage.

(H) Will increased temperature affect environmental management activities in petroleum industry?

19.4% of the survey results suggest that increased temperature will affect environmental management activities in petroleum industry significantly, 55.6% of the survey results indicate that the increased temperature affects environmental management activities in petroleum industry, 19.4% of the results suggest minor impact, 2.8% suggest no impact, and 2.8% of the survey results are not sure whether the increased temperature affects environmental management activities in petroleum industry or not.

> *Thus, the majority of survey results indicate increased temperature will affect environmental management activities in petroleum industry, a small portion of results indicate minor impacts on environmental management activities in petroleum industry.*

The sources of the survey results are from the follows:

- In the industry category, 36.5% of the individuals think that increased temperature will affect environmental management activities in petroleum industry, 51% of the individuals think that increased temperature will have minor impact on petroleum refining process, and 12.5% are not sure.

- In the government category, 57.1% of the individuals think that increased temperature will affect environmental management activities in petroleum industry significantly, 28.6% of the individuals think that increased temperature will have impact on petroleum refining process, and 14.3% suggest minor impacts.

- In the research organization category, 11.1% of the individuals think that increased temperature will affect environmental management activities in petroleum industry significantly, 72.2% of the individuals think that increased temperature will affect petroleum refining process, and 14.3% of the individuals think that increased temperature will have minor impact on petroleum refining process.

- In the non-governmental organization category, 33.3% think that environmental management activities in petroleum industry will be affected and 66.7% are not sure.

Among the individuals who think the increased temperature will affect environmental management activities in petroleum industry, 14.7% suggest no action, 5.9% think it is better to show concerns and be alerted, 11.8% want to conduct research and gain insight, 35.2% will conduct research and be prepared to take actions, and 32.4% begins to take adaptation actions.

The detailed adaptation actions are suggested as follows for this question:

17.9% suggest to investigate all possible impacts, update criteria of environmental management, 13.9% will use innovative remediation technology and develop new technology, 11.9% will take actions to reduce the oil leakage, spill, increase the treatment efficiency to lower the cost for pollution abatement, 12.6% will establish new environmental management policy to increase the pollution control efficiency, 9.9% will establish special environmental management system for petroleum industry, 7.9% will install recovery system to recycle, leakage oil, vapors back into operations, 5.96 will implement an on-line energy monitoring system, maximize energy efficiency, 7.9% will install a flare-reduction and emissions-recovery program, 4.6% will develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, fuels and fertilizer, and 7.3% will reinforce fire alarm and prevention system.

7.2. DISCUSSIONS

Clearly, climate-change impacts on petroleum industries are perceived differently in different companies and governmental organizations. This is due to differences in impacts on different industrial and governmental aspects. Those involved in in-door processing processes would perceive the impacts being minor or even positive; however, those involved in out-door processes and activities are mostly vulnerable to climate change.

Due to complicated interactions and extensive uncertainties associated with climatic and industrial factors, some impacts are considered insignificant. Further investigation is needed for improved clarity. Knowledge and insight on vulnerability of different parts of petroleum industry to climate change impacts can help to shed light on why oil and gas companies should be concerned about some particular impacts.

Clearly, the goals of petroleum industry are different from those of governmental and environmental agencies. However, the way in which the climate change impacts are portrayed by the governmental and environmental agencies and the methods they use to choose stories may have significant influences on industry's perceptions to climate change impacts.

In addition to the above discussion, in-depth analyses of the survey results from the second survey has been provided in section 7.3.

Table 7.4 Impacts of precipitation-patterns change

	Cost	Efficiency	Operation	pollutant emission
Negative	37%	39%	40%	51%
Positive	10%	6%	3%	8%
Both positive and negative	18%	15%	17%	21%
Unknown	45%	40%	40%	20%

Table 7.5 Impacts of increased natural hazards

	Cost	Efficiency	Operation	Pollutant emission
Negative	100%	100%	100%	100%
Positive	0%	0%	0%	0%
Both positive and negative	0%	0%	0%	0%
Unknown	0%	0%	0%	0%

7.3. CHI-SQUARE (χ^2) STATISTICAL TEST OF SURVEY INFORMATION

The Chi-square (χ^2) test has been performed in order to study how the surveyed persons responded in the survey and to validate the independence of the factors in terms of climate change impacts on the petroleum industry on the basis of the observed data.

The questionnaires which were used to study different persons' attitudes towards climate change impacts and adaptation strategies on petroleum industry, consist of a lot of categorical data. Analysis of categorical data generally involves the use of data tables. A contingency table which is a two-way table, can present categorical data by counting the number of observations that fall into each group for two variables, one divided into rows and the other divided into columns. The contingency table provides a foundation for statistical inference, where statistical tests question the relationship between the variables on the basis of the observed data.

The chi-square (χ^2) test provides a method for testing the association between the row and column variables in the contingency table. The null hypothesis H_0 assumes that there is no association between the variables, while the alternative hypothesis H_a claims that some association does exist. Assume that a sample of size N can be classified into *r* classes by the first variable and into *c* classes by the second, and the frequencies of individuals in each classification can be expressed as n_{rc}. The chi-square test is based on a test statistic that measures the divergence of the observed data from the values that would be expected under the null hypothesis of no association. This requires calculation of the expected values based on the data. The expected value for each cell in the contingency table is equal to (*row total*×*column total*)/N. Then the chi-square test statistic χ_c^2 can be formulated as follows (Kanji, 1993):

$$\chi_c^{\,2} = \sum_{i=1}^{r}\sum_{j=1}^{c}\frac{(n_{ij} - n_{i\bullet}n_{\bullet j}/N)^2}{n_{i\bullet}n_{\bullet j}/N}$$

$$n_{i\bullet} = \sum_{j=1}^{c} n_{ij}, \qquad i = 1,2,\ldots,r$$

$$n_{\bullet j} = \sum_{i=1}^{r} n_{ij}, \qquad j = 1,2,\ldots,c$$

The distribution of the statistic χ_c^2 is chi-square with (*r-1*)(*c-1*) degrees of freedom. The distribution is denoted as χ^2 (df), where df is the number of degrees of freedom. Once χ_c^2 is computed, it compares with the critical value which can be found using the table of χ^2 distribution with (*r-1*)(*c-1*) degrees of freedom. If χ_c^2 exceeds the critical value, the null hypothesis is rejected and the two variables are dependent on each other. Otherwise if χ_c^2 is smaller than the critical value, it can be concluded that the two variables are independent. Critical values for the hypothesis test depend on the test statistic and the significance level α, which defines the sensitivity of the test. A value of α= 0.05 implies that the null hypothesis is rejected 5% of the time when it is in fact true.

The choice of α is somewhat arbitrary, although in practice values of 0.1, 0.05, and 0.01 are common.

The calculation of χ_c^2 test statistic can be done by many software packages based on the above principles. Often, most software packages will report the test result as a *P*-value. The *P*-value for the chi-square test is $P(\chi^2 \geq \chi_c^2)$, the probability of observing a value at least as extreme as the test statistic for a chi-square distribution with $(r-1)(c-1)$ degrees of freedom. The *P*-value indicates the chance that one would obtain a test statistic which is more extreme than the observed one when the H_0 is true. Usually the *P*-value is compared against the level of significance α in the problem to decide whether or not to accept or reject the null hypothesis. If $P<\alpha$, the test statistic is in the rejection region and so we should reject H_0, that means that a small *P*-value is an indication of the false null hypothesis. Therefore, the general rule is that high *P*-values support H_0 and low *P*-values support H_a.

7.3.1. The association between the surveyed persons' background and the selection of climate change impacts

7.3.1.1.1. Temperature Impact on Petroleum Industry Processes

(1) Temperature Impact on Oil Exploration Processes

The observed occurrences of selection for impact (i.e., significant, some, minor, no impact, not sure) on oil exploration process, surveyed from the persons with different background (i.e., industry, government, research organization, non-governmental organization), are described in figure 7.1. From figure 7.1, we can draw conclusion that the surveyed persons tend to think that the increased temperature will have some impact on the oil exploration process.

In order to investigate whether or not there is any association between the impact selection and the surveyed persons' background, the chi-square χ^2 test was performed by using the software package Analyse-It®. The test result is shown in table 7.3.1, the cell entries in the contingency table are the observed data and the calculated expected value (which are in the parentheses). From table 7.3.1, we can find that the *P*-value is 0.1641, and this means that there is no association between the selection of temperature impacts on oil exploration process and the surveyed persons' background, under the significance level α=0.05.

Therefore, we can state that increased temperature tends to have some impacts on oil exploration process, and the surveyed person's background does not affect the selection of impacts.

(2) Temperature Impact on Drilling and Production Operation

Similarly, the survey and test results of temperature impact on drilling and production operation, are described by figure 7.2 and table 7.3.2. The surveyed persons who work in the governmental and research organizations tend to think that increased temperature has some impact on the drilling process, while the persons in the industrial organizations tend to think that the impact is minor. The calculated *P*-value is 0.0169, which means that there is some association between the selection of temperature impacts on drilling and production operation and the surveyed persons' background, under the significance level α=0.05.

Therefore, the surveyed person's background affect the selection of temperature impacts on drilling and production operation, and the impacts may tend to be some or minor.

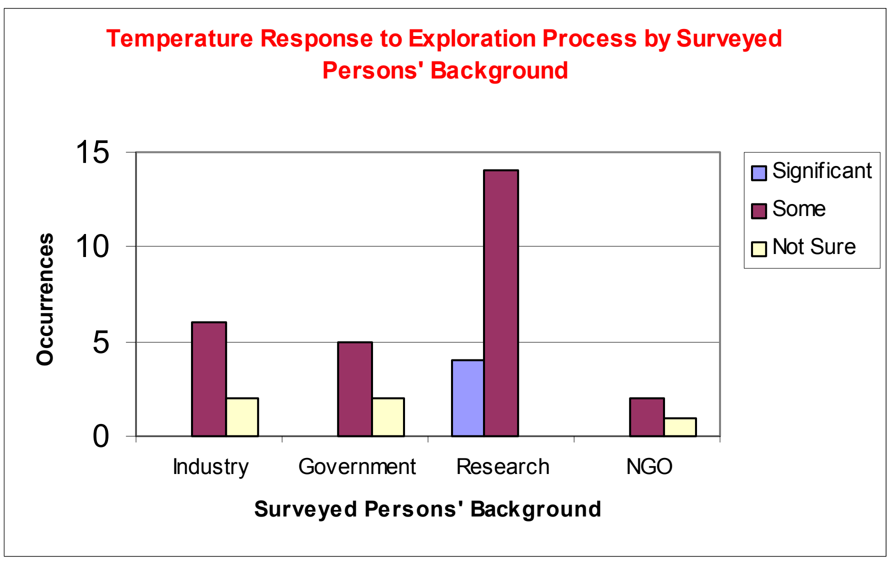


Figure 7.1 Temperature Response to Exploration Process by Surveyed Persons' Background

Table 7.3.1 Temperature Response to Exploration Process by Surveyed Persons' Background

Test	Chi-square test				
	Temperature Response to Exploration Process by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	Total
Significant	0 (0.9)	0 (0.8)	4 (2.0)	0 (0.3)	**4**
Some	6 (6.0)	5 (5.3)	14 (13.5)	2 (2.3)	**27**
Not Sure	2 (1.1)	2 (1.0)	0 (2.5)	1 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	9.17				
p	0.1641				

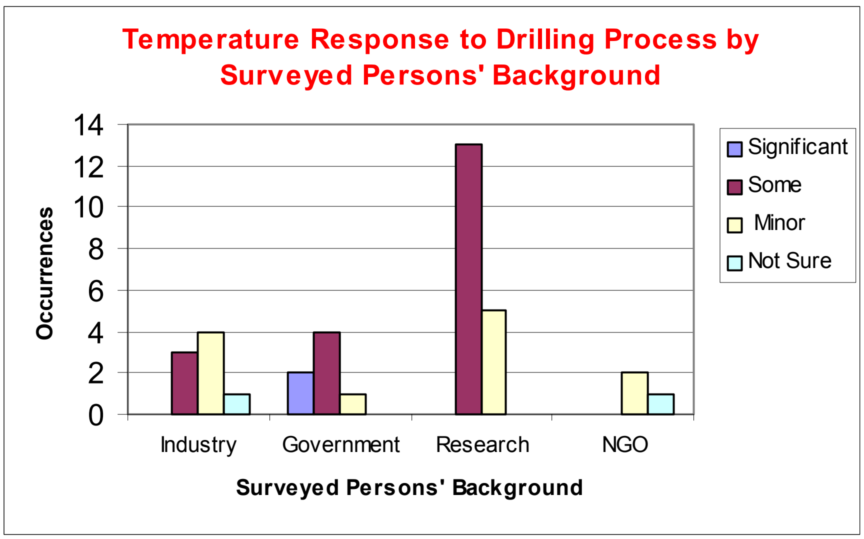


Figure 7.2 Temperature Response to Drilling Process by Surveyed Persons' Background

Table 7.3.2 Temperature Response to Drilling Process by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Drilling and Production operation by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.4)	2 (0.4)	0 (1.0)	0 (0.2)	**2**
Some	3 (4.4)	4 (3.9)	13 (10.0)	0 (1.7)	**20**
Minor	4 (2.7)	1 (2.3)	5 (6.0)	2 (1.0)	**12**
Not Sure	1 (0.4)	0 (0.4)	0 (1.0)	1 (0.2)	**2**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	20.17				
p	0.0169				

(3) Temperature Impact on Exploration and Production Infrastructures

The survey and test results of temperature impact on exploration and production infrastructures, are described by figure 7.3 and table 7.3.3. The surveyed persons tend to think that increased temperature has some impact on exploration and production infrastructures. The calculated P-value is 0.0554, which means that there is weak association (or no association) between the selection of temperature impacts on exploration and production infrastructures and the surveyed persons' background, under the significance level α=0.05.

Therefore, the surveyed person's background only slightly (or even not) affect the selection of temperature impacts on exploration and production infrastructures, and the impacts may tend to be some.

(4) Temperature Impact on Transportation Activities within Exploration and Production Processes

The survey and test results of temperature impact on transportation activities within exploration and production processes, are described by figure 7.4 and table 7.3.4. The surveyed persons tend to think that increased temperature has some impact on transportation activities. The calculated P-value is 0.1804, which means that there is no association between the selection of temperature impacts on transportation activities and the surveyed persons' background, under the significance level α=0.05.

Therefore, the surveyed person's background does not affect the selection of temperature impacts on transportation activities within exploration and production processes, and the impacts tend to be some.

(5) Temperature Impact on Cost of Exploration and Production

The survey and test results of temperature impact on cost of exploration and production, are described by figure 7.5 and table 7.3.5. The surveyed persons tend to think that increased temperature has some impact on exploration and production cost. The calculated P-value is 0.1433, which means that there is no association between the selection of temperature impacts on exploration cost and the surveyed persons' background, under the significance level α=0.05.

Therefore, the surveyed person's background does not affect the selection of temperature impacts on exploration and production cost, and the impacts tend to be some.

(6) Temperature Impact on Petroleum Refining Process

The survey and test results of temperature impact on petroleum refining process, are described by figure 7.6 and table 7.3.6. The opinions are totally different based on the background of surveyed persons. However, the calculated P-value is 0.408, which means that there is no association between the selection of temperature impacts on petroleum refining process and the surveyed persons' background, under the significance level α=0.05.

Therefore, the surveyed person's background does not affect the selection of temperature impacts on petroleum refining process, and the phenomenon of scattered opinions may be from random errors.

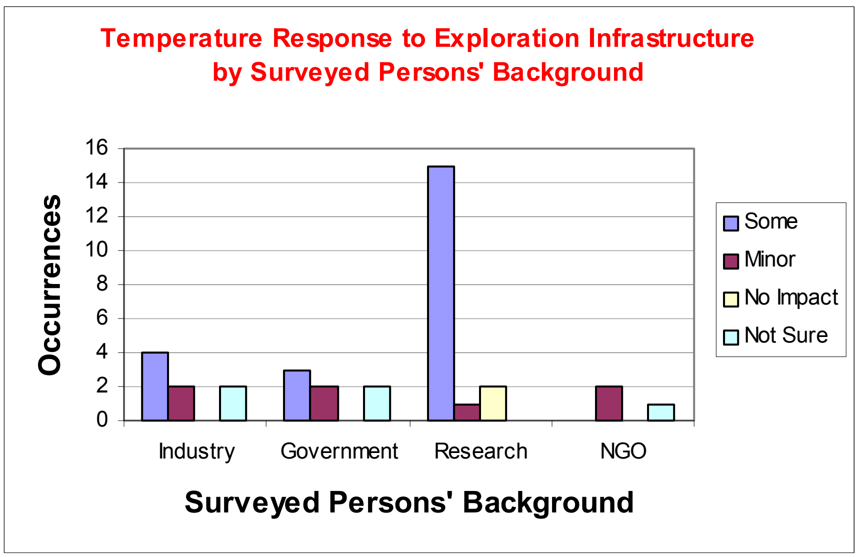


Figure 7.3 Temperature Response to Exploration Infrastructure by Surveyed Persons' Background

Table 7.3.3 Temperature Response to Exploration Infrastructures by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Exploration Infrastructure by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Some	4 (4.9)	3 (4.3)	15 (11.0)	0 (1.8)	**22**
Minor	2 (1.6)	2 (1.4)	1 (3.5)	2 (0.6)	**7**
No Impact	0 (0.4)	0 (0.4)	2 (1.0)	0 (0.2)	**2**
Not Sure	2 (1.1)	2 (1.0)	0 (2.5)	1 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	16.60				
p	0.0554				

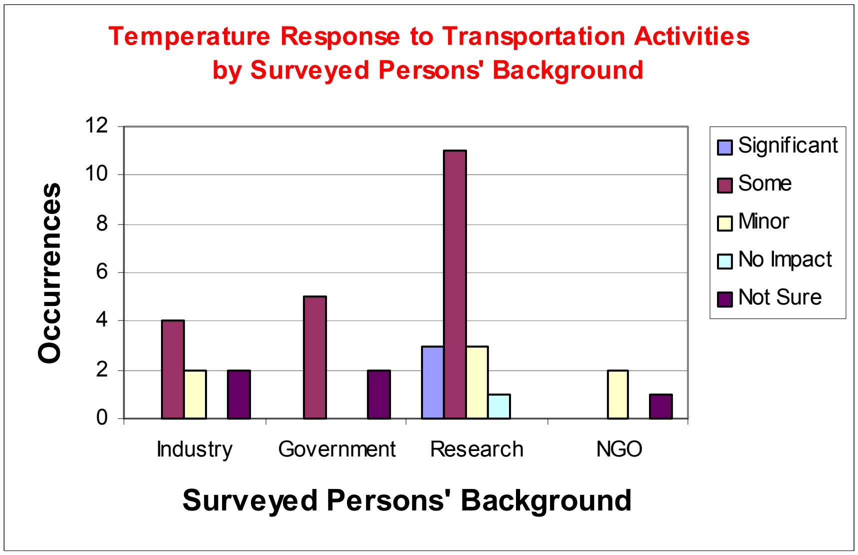


Figure 7.4 Temperature Response to Transportation Activities by Surveyed Persons' Background

Table 7.3.4 Temperature Response to Transportation Activities by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Transportation Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.7)	0 (0.6)	3 (1.5)	0 (0.3)	**3**
Some	4 (4.4)	5 (3.9)	11 (10.0)	0 (1.7)	**20**
Minor	2 (1.6)	0 (1.4)	3 (3.5)	2 (0.6)	**7**
No Impact	0 (0.2)	0 (0.2)	1 (0.5)	0 (0.1)	**1**
Not Sure	2 (1.1)	2 (1.0)	0 (2.5)	1 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	16.24				
p	0.1804				

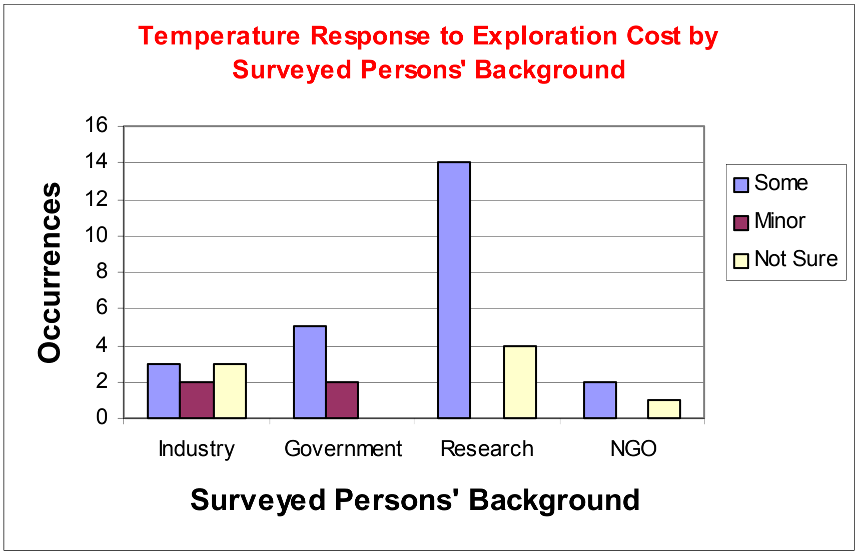


Figure 7.5 Temperature Response to Exploration Cost by Surveyed Persons' Background

Table 7.3.5 Temperature Response to Exploration Cost by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Exploration Cost by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Some	3 (5.3)	5 (4.7)	14 (12.0)	2 (2.0)	**24**
Minor	2 (0.9)	2 (0.8)	0 (2.0)	0 (0.3)	**4**
Not Sure	3 (1.8)	0 (1.6)	4 (4.0)	1 (0.7)	**8**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	9.58				
p	0.1433				

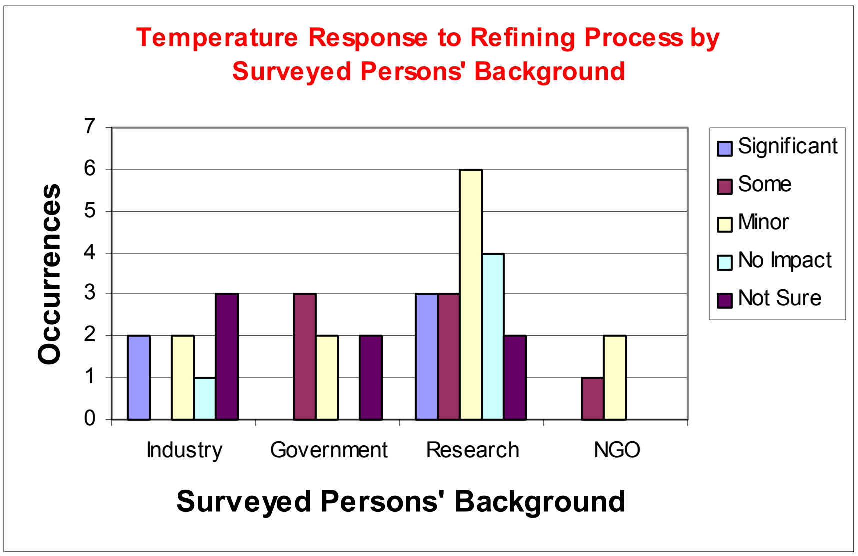


Figure 7.6 Temperature Response to Refining Process by Surveyed Persons' Background

Table 7.3.6 Temperature Response to Refining Process by Surveyed Persons' Background

Test	Chi-square test
	Temperature Response to Refining Process by Surveyed Persons' Background
Performed by	EVSE, U of Regina
n	36

Data Response	Surveyed Persons' Background Industry	Government	Research	NGO	Total
Significant	2 (1.1)	0 (1.0)	3 (2.5)	0 (0.4)	**5**
Some	0 (1.6)	3 (1.4)	3 (3.5)	1 (0.6)	**7**
Minor	2 (2.7)	2 (2.3)	6 (6.0)	2 (1.0)	**12**
No Impact	1 (1.1)	0 (1.0)	4 (2.5)	0 (0.4)	**5**
Not Sure	3 (1.6)	2 (1.4)	2 (3.5)	0 (0.6)	**7**
Total	**8**	**7**	**18**	**3**	**36**

X^2 statistic	12.48
p	0.4080

(7) Temperature Impact on Pollutant Emission within Oil Refinery Process

The survey and test results of temperature impact on petroleum refinery pollution emission, are described by figure 7.7 and table 7.3.7. The opinions are different based on the background of surveyed persons. The persons in governmental and research organizations tend to think that the impacts are significant and some, respectively. The calculated *P*-value is 0.0044, which means that there is really association between the selection of temperature impacts on petroleum refinery pollution and the surveyed persons' background, under the significance level $\alpha=0.05$.

Therefore, the surveyed person's background affect the selection of temperature impacts on pollutant emission within oil refinery process.

(8) Temperature Impact on Petroleum Transportation and Storage

The survey and test results of temperature impact on petroleum transportation and storage, are described by figure 7.8 and table 7.3.8. The impacts tend to be some or minor. The calculated *P*-value is 0.1257, which means that there is no association between the selection of temperature impacts on petroleum transportation and storage and the surveyed persons' background, under the significance level $\alpha=0.05$.

Therefore, the surveyed person's background doesn't affect the selection of temperature impacts on petroleum transportation and storage, and the impacts tend to be some or minor.

(9) Temperature Impact on Cost of Transportation and Storage

The survey and test results of temperature impact on petroleum transportation and storage cost, are described by figure 7.9 and table 7.3.9. The impacts tend to be some or minor. The calculated *P*-value is 0.1304, which means that there is no association between the selection of temperature impacts on petroleum transportation and storage cost and the surveyed persons' background, under the significance level $\alpha=0.05$.

Therefore, the surveyed person's background doesn't affect the selection of temperature impacts on petroleum transportation and storage cost, and the impacts tend to be some or minor.

(10) Temperature Impact on Environmental Management Activities in Petroleum Industry

The survey and test results of temperature impact on environmental management activities in petroleum industry, are described by figure 7.10 and table 7.3.10. The persons in industrial, governmental and research organizations think that the impacts tend to be minor, significant and some, respectively. The calculated *P*-value is 0.0744, which means that there is only slight association (or no association) between the selection of temperature impacts on environmental management activities in petroleum industry and the surveyed persons' background, under the significance level $\alpha=0.05$.

Therefore, the surveyed person's background only slightly (or doesn't) affect the selection of temperature impacts on environmental management activities in petroleum industry.

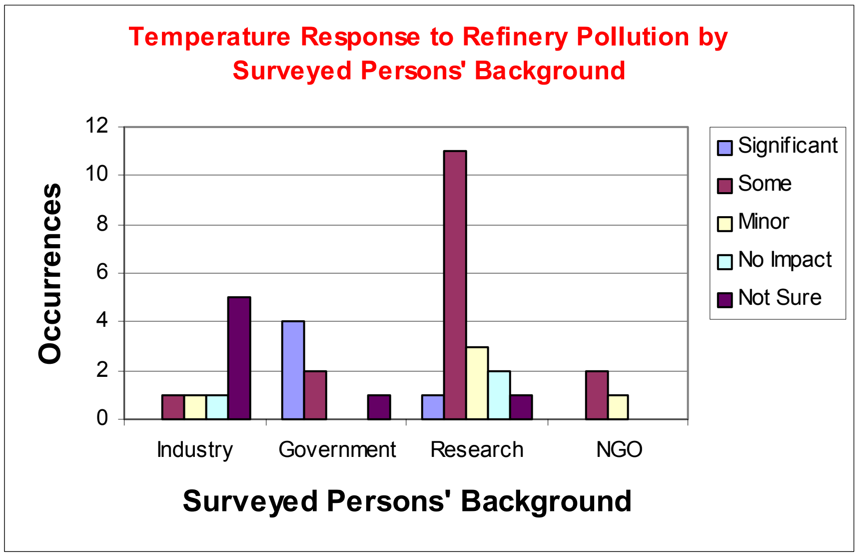


Figure 7.7 Temperature Response to Refinery Pollution by Surveyed Persons' Background

Table 7.3.7 Temperature Response to Refinery Pollution by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Refinery Pollution by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (1.1)	4 (1.0)	1 (2.5)	0 (0.4)	**5**
Some	1 (3.6)	2 (3.1)	11 (8.0)	2 (1.3)	**16**
Minor	1 (1.1)	0 (1.0)	3 (2.5)	1 (0.4)	**5**
No Impact	1 (0.7)	0 (0.6)	2 (1.5)	0 (0.3)	**3**
Not Sure	5 (1.6)	1 (1.4)	1 (3.5)	0 (0.6)	**7**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	28.71				
p	0.0044				

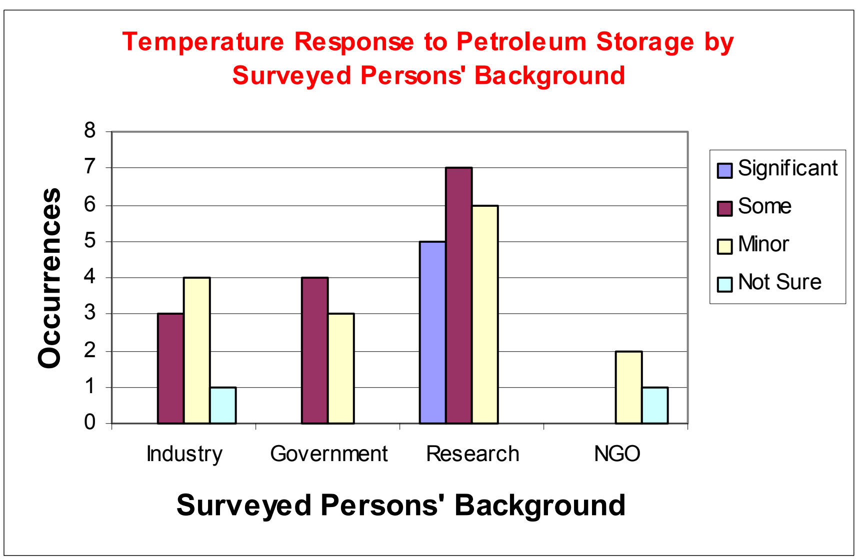


Figure 7.8 Temperature Response to Petroleum Storage by Surveyed Persons' Background

Table 7.3.8 Temperature Response to Petroleum Storage by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Petroleum Storage by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (1.1)	0 (1.0)	5 (2.5)	0 (0.4)	**5**
Some	3 (3.1)	4 (2.7)	7 (7.0)	0 (1.2)	**14**
Minor	4 (3.3)	3 (2.9)	6 (7.5)	2 (1.3)	**15**
Not Sure	1 (0.4)	0 (0.4)	0 (1.0)	1 (0.2)	**2**
Total	**8**	**7**	**18**	**3**	**36**
X² statistic	13.91				
p	0.1257				

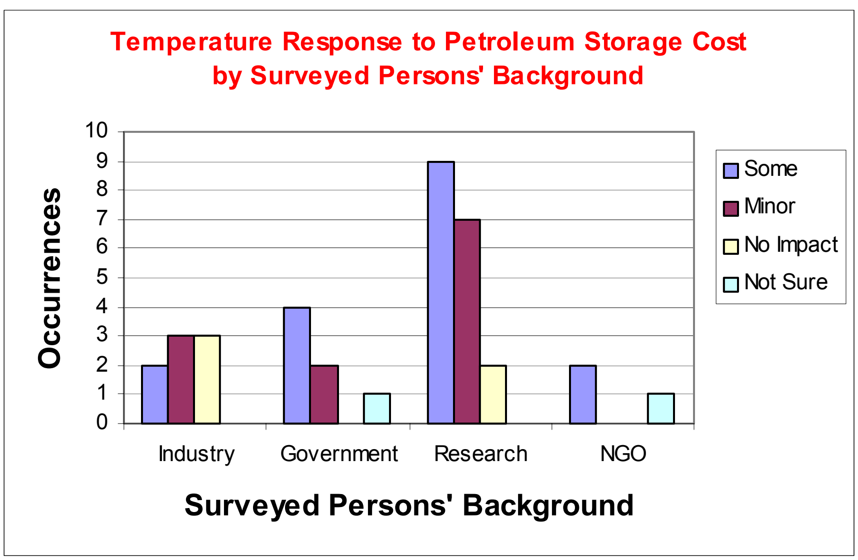


Figure 7.9 Temperature Response to Petroleum Storage Cost by Surveyed Persons' Background

Table 7.3.9 Temperature Response to Petroleum Storage Cost by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Petroleum Storage Cost by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Some	2 (3.8)	4 (3.3)	9 (8.5)	2 (1.4)	**17**
Minor	3 (2.7)	2 (2.3)	7 (6.0)	0 (1.0)	**12**
No Impact	3 (1.1)	0 (1.0)	2 (2.5)	0 (0.4)	**5**
Not Sure	0 (0.4)	1 (0.4)	0 (1.0)	1 (0.2)	**2**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	13.78				
p	0.1304				

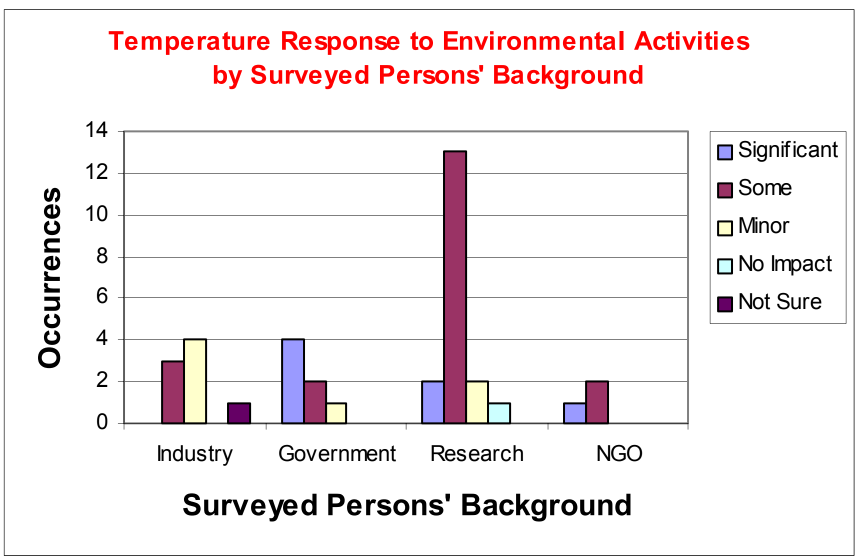


Figure 7.10 Temperature Response to Environmental Activities by Surveyed Persons' Background

Table 7.3.10 Temperature Response to Environmental Activities by Surveyed Persons' Background

Test	**Chi-square test**				
	Temperature Response to Environmental Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (1.6)	4 (1.4)	2 (3.5)	1 (0.6)	**7**
Some	3 (4.4)	2 (3.9)	13 (10.0)	2 (1.7)	**20**
Minor	4 (1.6)	1 (1.4)	2 (3.5)	0 (0.6)	**7**
No Impact	0 (0.2)	0 (0.2)	1 (0.5)	0 (0.1)	**1**
Not Sure	1 (0.2)	0 (0.2)	0 (0.5)	0 (0.1)	**1**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	19.63				
p	0.0744				

7.3.1.2. Precipitation Impact on Petroleum Industry Processes

The survey and test results of precipitation impacts on petroleum industry processes, are described by figures 7.3.11 through 7.3.20 and tables 7.3.11 through 7.3.20.

We can obtain some conclusions from these figures and test results:

1. The changed precipitation tends to have some or minor impacts on oil exploration process, and the surveyed person's background slightly affect the selection of impacts;
2. The changed precipitation tends to have some or minor impacts on drilling and production operations, and the surveyed person's background doesn't affect the selection of impacts;
3. The changed precipitation tends to have different impacts (significant, some, minor, no impact) on exploration and production infrastructures, and the surveyed person's background affect the selection of impacts;
4. The changed precipitation tends to have different impacts (significant, some, minor, no impact) on transportation activities within exploration and production processes, and the surveyed person's background affect the selection of impacts;
5. The changed precipitation tends to have significant or some impacts on cost of exploration and production, and the surveyed person's background doesn't affect the selection of impacts;
6. The changed precipitation tends to have some or no impacts on petroleum refining process, and the surveyed person's background slightly affect the selection of impacts;
7. The changed precipitation tends to have some impacts or the surveyed persons are not sure the impacts on pollutant emission within oil refinery process, and the surveyed person's background doesn't affect the selection of impacts;
8. The changed precipitation tends to have some or minor impacts on petroleum transportation and storage, and the surveyed person's background affect the selection of impacts;
9. The changed precipitation tends to have different impacts (significant, some, minor, no impact, not sure) on petroleum transportation and storage cost, and the surveyed person's background strongly affect the selection of impacts;
10. The changed precipitation tends to have different impacts (significant, some, minor, no impact, not sure) on environmental management activities in petroleum industry, and the surveyed person's background strongly affect the selection of impacts.

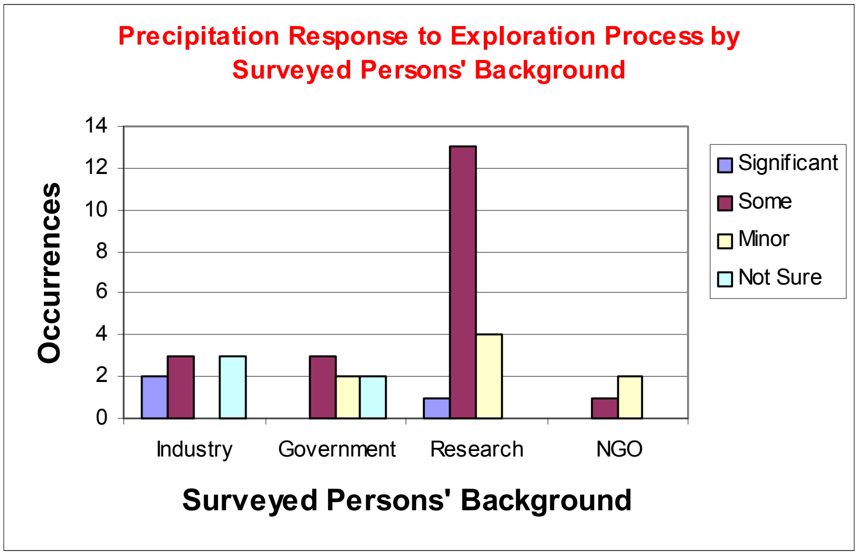


Figure 7.11 Precipitation Response to Exploration Process by Surveyed Persons' Background

Table 7.3.11 Precipitation Response to Exploration Process by Surveyed Persons' Background

Test	Chi-square test				
	Precipitation Response to Exploration Process by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	Total
Significant	2 (0.7)	0 (0.6)	1 (1.5)	0 (0.3)	**3**
Some	3 (4.4)	3 (3.9)	13 (10.0)	1 (1.7)	**20**
Minor	0 (1.8)	2 (1.6)	4 (4.0)	2 (0.7)	**8**
Not Sure	3 (1.1)	2 (1.0)	0 (2.5)	0 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	17.29				
p	0.0443				

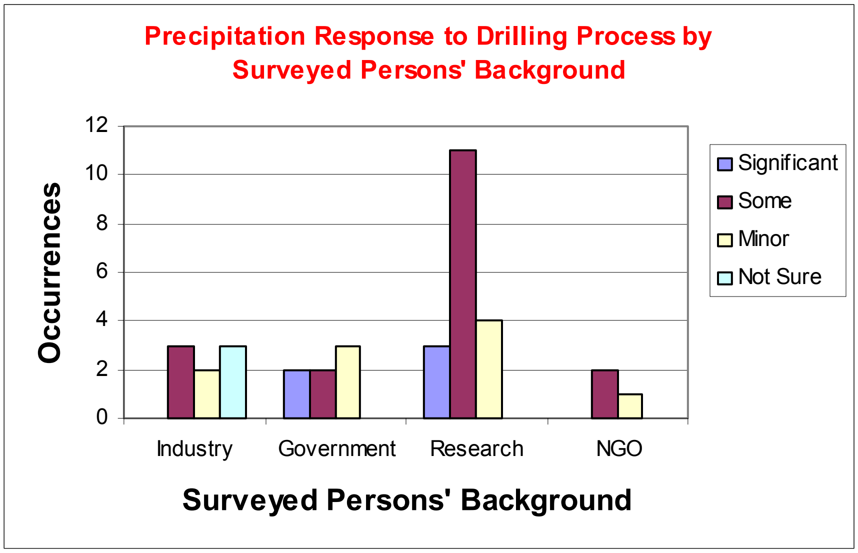


Figure 7.12 Precipitation Response to Drilling Process by Surveyed Persons' Background

Table 7.3.12 Precipitation Response to Drilling Process by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Drilling Process by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (1.1)	2 (1.0)	3 (2.5)	0 (0.4)	**5**
Some	3 (4.0)	2 (3.5)	11 (9.0)	2 (1.5)	**18**
Minor	2 (2.2)	3 (1.9)	4 (5.0)	1 (0.8)	**10**
Not Sure	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	15.55				
p	0.0770				

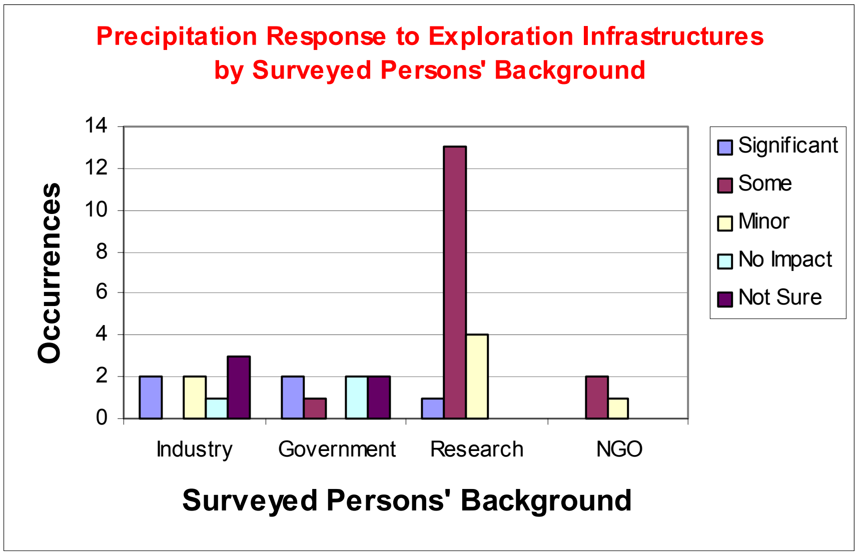


Figure 7.13 Precipitation Response to Exploration Infrastructures by Surveyed Persons' Background

Table 7.3.13 Precipitation Response to Exploration Infrastructures by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Exploration Infrastructure by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	2 (1.1)	2 (1.0)	1 (2.5)	0 (0.4)	**5**
Some	0 (3.6)	1 (3.1)	13 (8.0)	2 (1.3)	**16**
Minor	2 (1.6)	0 (1.4)	4 (3.5)	1 (0.6)	**7**
No Impact	1 (0.7)	2 (0.6)	0 (1.5)	0 (0.3)	**3**
Not Sure	3 (1.1)	2 (1.0)	0 (2.5)	0 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X² statistic	25.99				
p	0.0108				

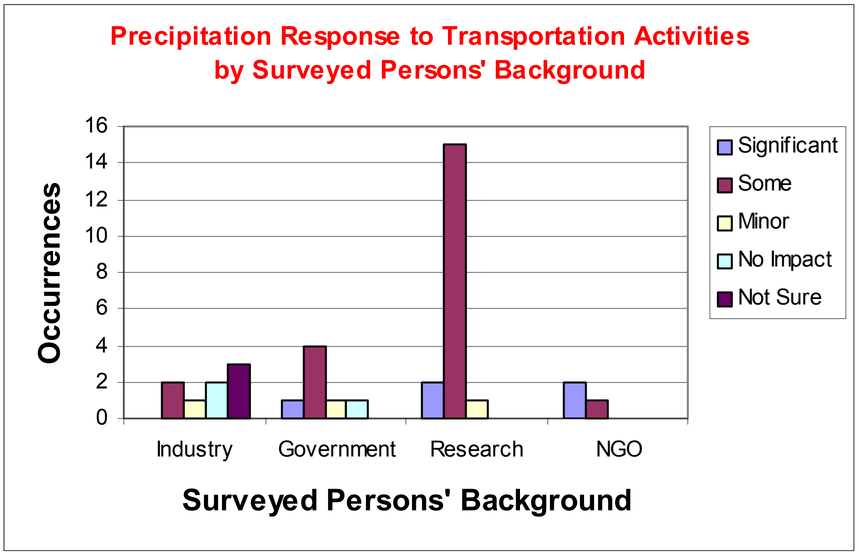


Figure 7.14 Precipitation Response to Transportation Activities by Surveyed Persons' Background

Table 7.3.14 Precipitation Response to Transportation Activities by Surveyed Persons' Background

Test	Chi-square test				
	Precipitation Response to Transportation Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	Total
Significant	0 (1.1)	1 (1.0)	2 (2.5)	2 (0.4)	**5**
Some	2 (4.9)	4 (4.3)	15 (11.0)	1 (1.8)	**22**
Minor	1 (0.7)	1 (0.6)	1 (1.5)	0 (0.3)	**3**
No Impact	2 (0.7)	1 (0.6)	0 (1.5)	0 (0.3)	**3**
Not Sure	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X² statistic	26.88				
p	0.0080				

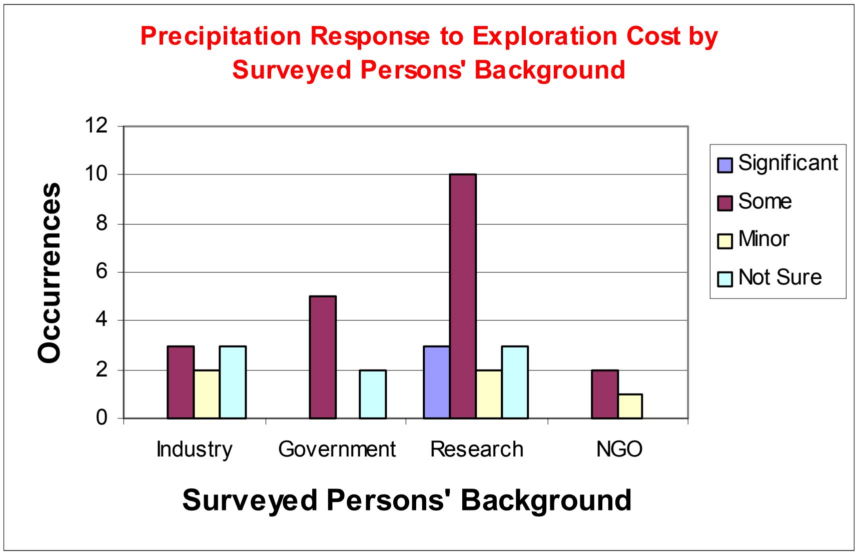


Figure 7.15 Precipitation Response to Exploration Cost by Surveyed Persons' Background

Table 7.3.15 Precipitation Response to Exploration Cost by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Exploration Cost by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.7)	0 (0.6)	3 (1.5)	0 (0.3)	**3**
Some	3 (4.4)	5 (3.9)	10 (10.0)	2 (1.7)	**20**
Minor	2 (1.1)	0 (1.0)	2 (2.5)	1 (0.4)	**5**
Not Sure	3 (1.8)	2 (1.6)	3 (4.0)	0 (0.7)	**8**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	8.34				
p	0.5005				

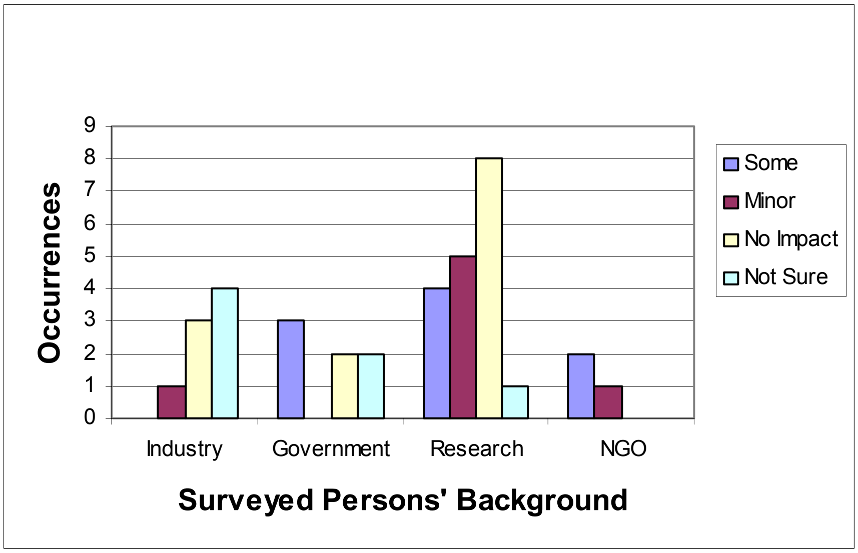


Figure 7.16 Precipitation Response to Refining Process by Surveyed Persons' Background

Table 7.3.16 Precipitation Response to Refining Process by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Refining Process by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Some	0 (2.0)	3 (1.8)	4 (4.5)	2 (0.8)	**9**
Minor	1 (1.6)	0 (1.4)	5 (3.5)	1 (0.6)	**7**
No Impact	3 (2.9)	2 (2.5)	8 (6.5)	0 (1.1)	**13**
Not Sure	4 (1.6)	2 (1.4)	1 (3.5)	0 (0.6)	**7**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	15.59				
p	0.0760				

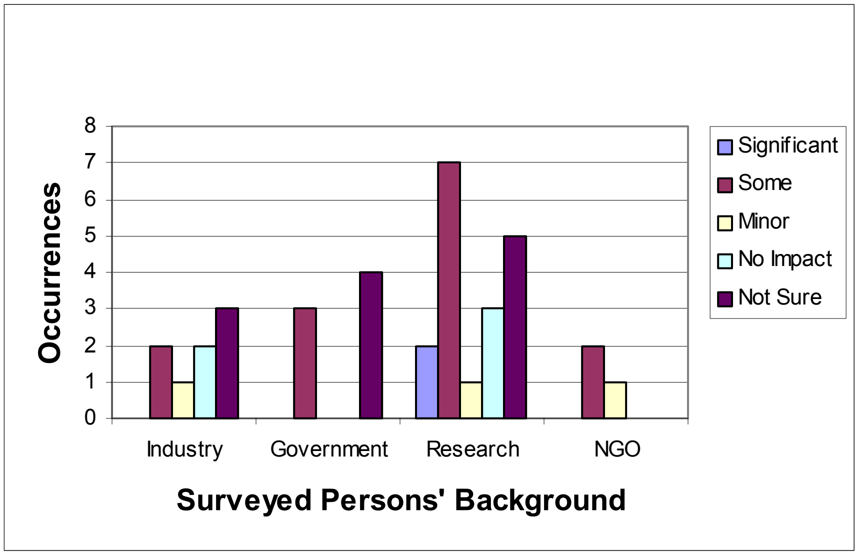


Figure 7.17 Precipitation Response to Refinery Pollution by Surveyed Persons' Background

Table 7.3.17 Precipitation Response to Refinery Pollution by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Refinery Pollution by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.4)	0 (0.4)	2 (1.0)	0 (0.2)	**2**
Some	2 (3.1)	3 (2.7)	7 (7.0)	2 (1.2)	**14**
Minor	1 (0.7)	0 (0.6)	1 (1.5)	1 (0.3)	**3**
No Impact	2 (1.1)	0 (1.0)	3 (2.5)	0 (0.4)	**5**
Not Sure	3 (2.7)	4 (2.3)	5 (6.0)	0 (1.0)	**12**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	10.79				
p	0.5474				

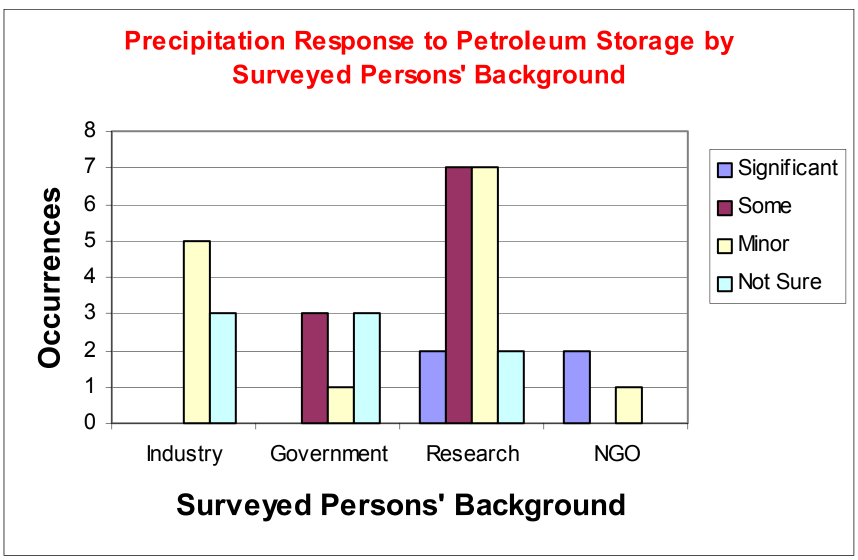


Figure 7.18 Precipitation Response to Petroleum Storage by Surveyed Persons' Background

Table 7.3.18 Precipitation Response to Petroleum Storage by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Petroleum Storage by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.9)	0 (0.8)	2 (2.0)	2 (0.3)	**4**
Some	0 (2.2)	3 (1.9)	7 (5.0)	0 (0.8)	**10**
Minor	5 (3.1)	1 (2.7)	7 (7.0)	1 (1.2)	**14**
Not Sure	3 (1.8)	3 (1.6)	2 (4.0)	0 (0.7)	**8**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	20.54				
p	0.0149				

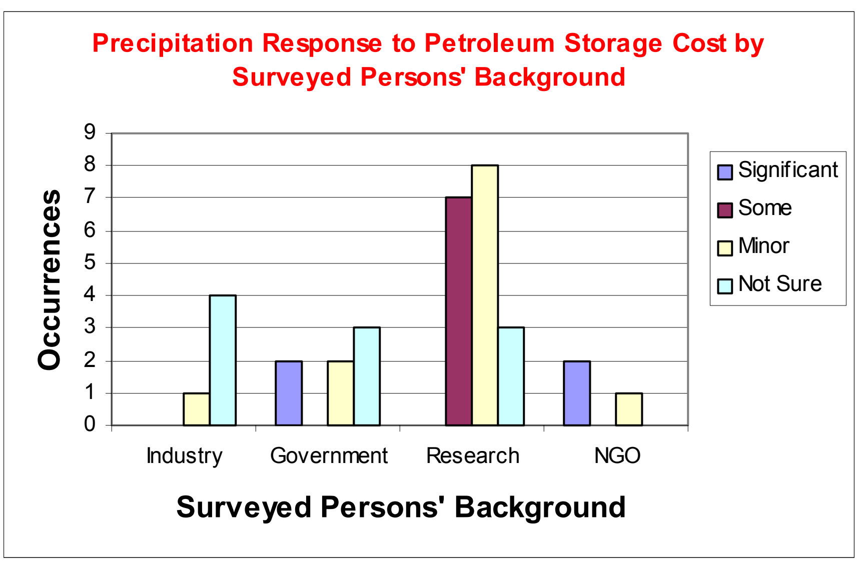


Figure 7.19 Precipitation Response to Petroleum Storage Cost by Surveyed Persons' Background

Table 7.3.19 Precipitation Response to Petroleum Storage Cost by Surveyed Persons' Background

Test	**Chi-square test**
	Precipitation Response to Petroleum Storage Cost by Surveyed Persons' Background
Performed by	EVSE, U of Regina
n	36

Data Response	**Surveyed Persons' Background** Industry	Government	Research	NGO	**Total**
Significant	0 (0.9)	2 (0.8)	0 (2.0)	2 (0.3)	**4**
Some	0 (1.6)	0 (1.4)	7 (3.5)	0 (0.6)	**7**
Minor	1 (2.7)	2 (2.3)	8 (6.0)	1 (1.0)	**12**
No Impact	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Not Sure	4 (2.2)	3 (1.9)	3 (5.0)	0 (0.8)	**10**
Total	**8**	**7**	**18**	**3**	**36**

X^2 statistic	36.03
p	0.0003

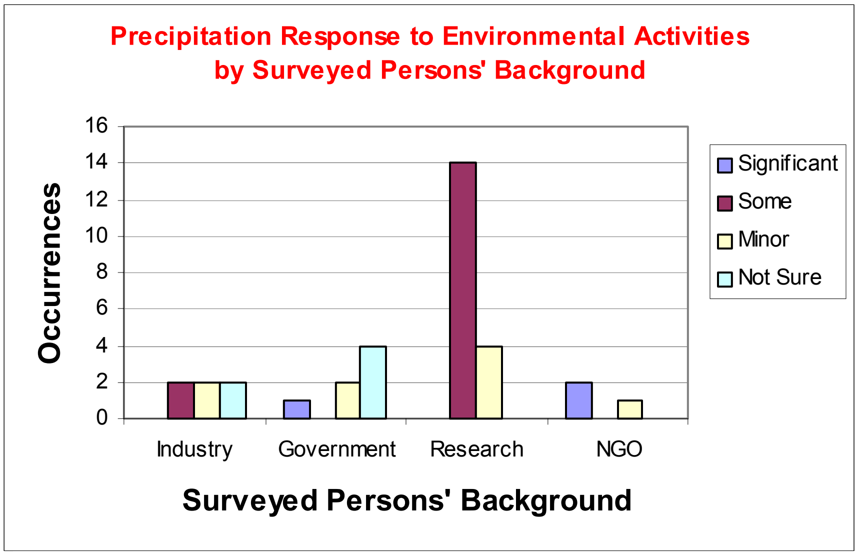


Figure 7.20 Precipitation Response to Environmental Activities by Surveyed Persons' Background

Table 7.3.20 Precipitation Response to Environmental Activities by Surveyed Persons' Background

Test	**Chi-square test**				
	Precipitation Response to Environmental Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.7)	1 (0.6)	0 (1.5)	2 (0.3)	**3**
Some	2 (3.6)	0 (3.1)	14 (8.0)	0 (1.3)	**16**
Minor	2 (2.0)	2 (1.8)	4 (4.5)	1 (0.8)	**9**
No Impact	2 (0.4)	0 (0.4)	0 (1.0)	0 (0.2)	**2**
Not Sure	2 (1.3)	4 (1.2)	0 (3.0)	0 (0.5)	**6**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	42.23				
p	<0.0001				

7.3.1.3. Natural Hazard Impact on Petroleum Industry Processes

The survey and test results of natural hazard impacts on petroleum industry processes, are described by figures 7.3.21 through 7.3.30 and tables 7.3.21 through 7.3.30.

We can obtain some conclusions from these figures and test results:

1. The natural hazard introduced by climate change tends to have different impacts (significant, some, minor) on oil exploration processes, and the surveyed person's background strongly affect the selection of impacts;
2. The natural hazard tends to have significant or some impacts on drilling and production operations, and the surveyed person's background doesn't affect the selection of impacts;
3. The natural hazard tends to have significant or some impacts on exploration and production infrastructures, but the surveyed person's background doesn't affect the selection of impacts;
4. The natural hazard tends to have different impacts (significant, some, minor) on transportation activities within exploration and production processes, and the surveyed person's background affects the selection of impacts;
5. The natural hazard tends to have different impacts (significant, some, minor, not sure) on cost of exploration and production, and the surveyed person's background strongly affect the selection of impacts;
6. The natural hazard tends to have some impacts on petroleum refining process, and the surveyed person's background doesn't affect the selection of impacts;
7. The natural hazard tends to have different impacts (significant, some, not sure) on pollutant emission within oil refinery process, and the surveyed person's background strongly affect the selection of impacts;
8. The natural hazard tends to have some impacts on petroleum transportation and storage, and the surveyed person's background doesn't affect the selection of impacts;
9. The natural hazard tends to have some or minor impacts on petroleum transportation and storage cost, and the surveyed person's background slightly doesn't affect the selection of impacts;
10. The natural hazard tends to have some impacts on environmental management activities in petroleum industry, and the surveyed person's background doesn't affect the selection of impacts.

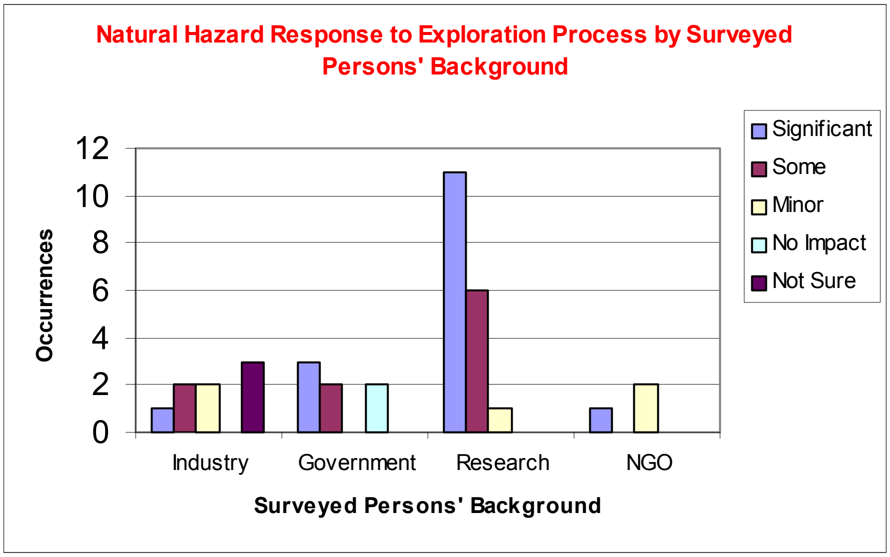


Figure 7.21 Natural Hazard Response to Exploration Process by Surveyed Persons' Background

Table 7.3.21 Natural Hazard Response to Exploration Process by Surveyed Persons' Background

Test	**Chi-square test**				
Performed by	Natural Hazard Response to Exploration Process by Surveyed Persons' Background EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	1 (3.6)	3 (3.1)	11 (8.0)	1 (1.3)	**16**
Some	2 (2.2)	2 (1.9)	6 (5.0)	0 (0.8)	**10**
Minor	2 (1.1)	0 (1.0)	1 (2.5)	2 (0.4)	**5**
No Impact	0 (0.4)	2 (0.4)	0 (1.0)	0 (0.2)	**2**
Not Sure	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	31.49				
p	0.0017				

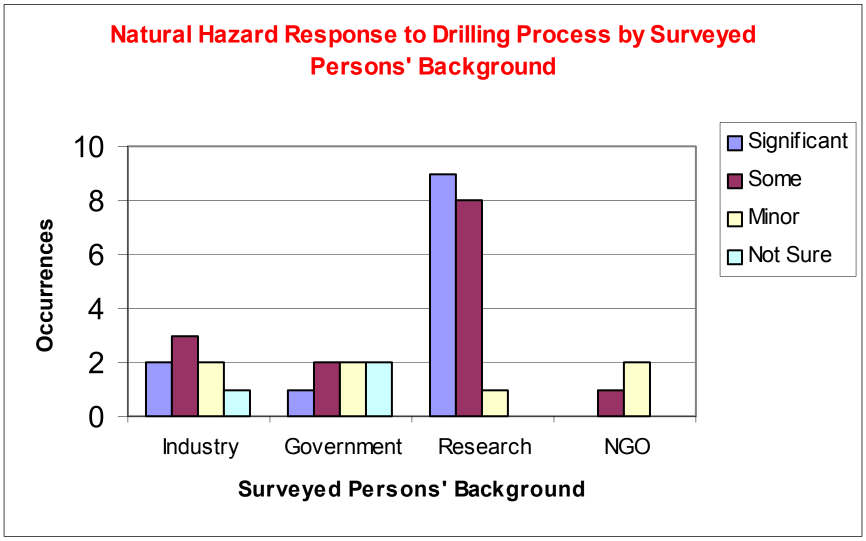


Figure 7.22 Natural Hazard Response to Drilling Process by Surveyed Persons' Background

Table 7.3.22 Natural Hazard Response to Drilling Process by Surveyed Persons' Background

Test	Chi-square test				
	Natural Hazard Response to Drilling Process by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	Total
Significant	2 (2.7)	1 (2.3)	9 (6.0)	0 (1.0)	**12**
Some	3 (3.1)	2 (2.7)	8 (7.0)	1 (1.2)	**14**
Minor	2 (1.6)	2 (1.4)	1 (3.5)	2 (0.6)	**7**
Not Sure	1 (0.7)	2 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	14.80				
p	0.0965				

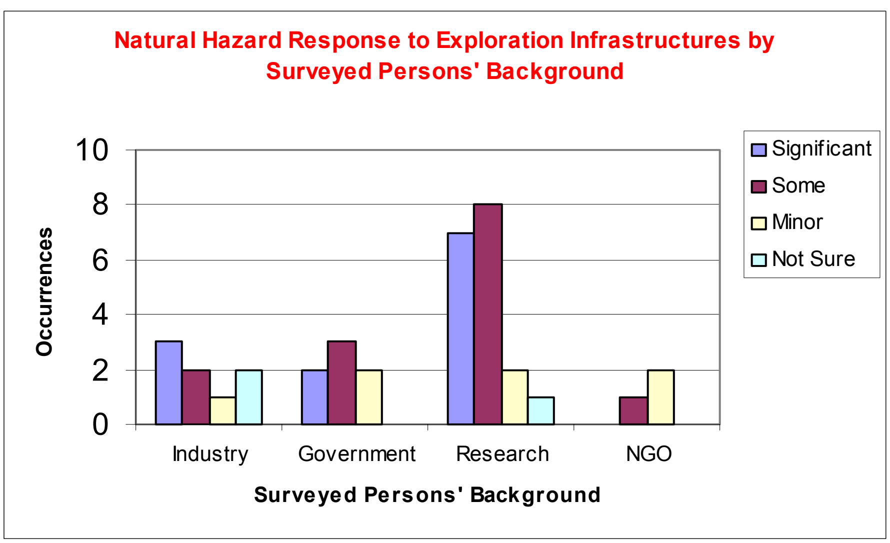


Figure 7.23 Natural Hazard Response to Exploration Infrastructures by Surveyed Persons' Background

Table 7.3.23 Natural Hazard Response to Exploration Infrastructures by Surveyed Persons' Background

Test	**Chi-square test**				
	Natural Hazard Response to Exploration Infrastructures by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	3 (2.7)	2 (2.3)	7 (6.0)	0 (1.0)	**12**
Some	2 (3.1)	3 (2.7)	8 (7.0)	1 (1.2)	**14**
Minor	1 (1.6)	2 (1.4)	2 (3.5)	2 (0.6)	**7**
Not Sure	2 (0.7)	0 (0.6)	1 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	10.10				
p	0.3428				

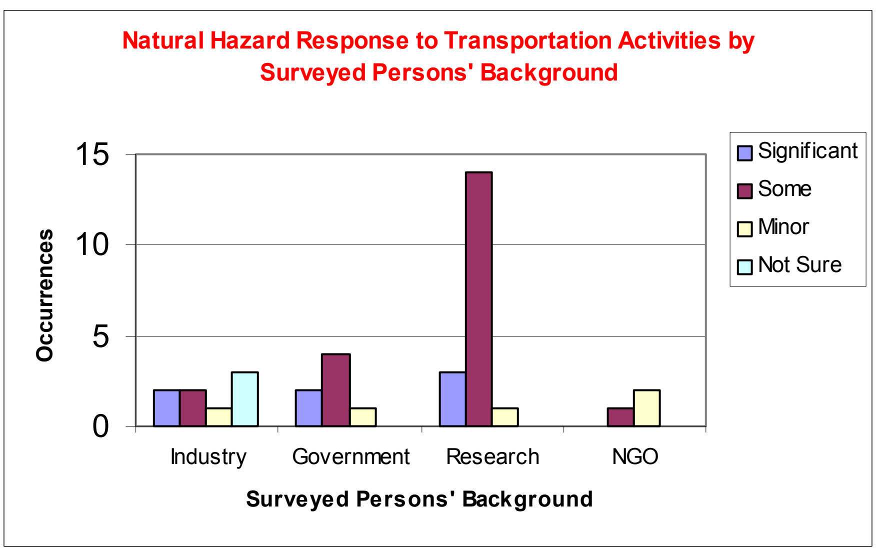


Figure 7.24 Natural Hazard Response to Transportation Activities by Surveyed Persons' Background

Table 7.3.24 Natural Hazard Response to Transportation Activities by Surveyed Persons' Background

Test	**Chi-square test**				
	Natural Hazard Response to Transportation Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	2 (1.6)	2 (1.4)	3 (3.5)	0 (0.6)	**7**
Some	2 (4.7)	4 (4.1)	14 (10.5)	1 (1.8)	**21**
Minor	1 (1.1)	1 (1.0)	1 (2.5)	2 (0.4)	**5**
Not Sure	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X² statistic	21.52				
p	0.0105				

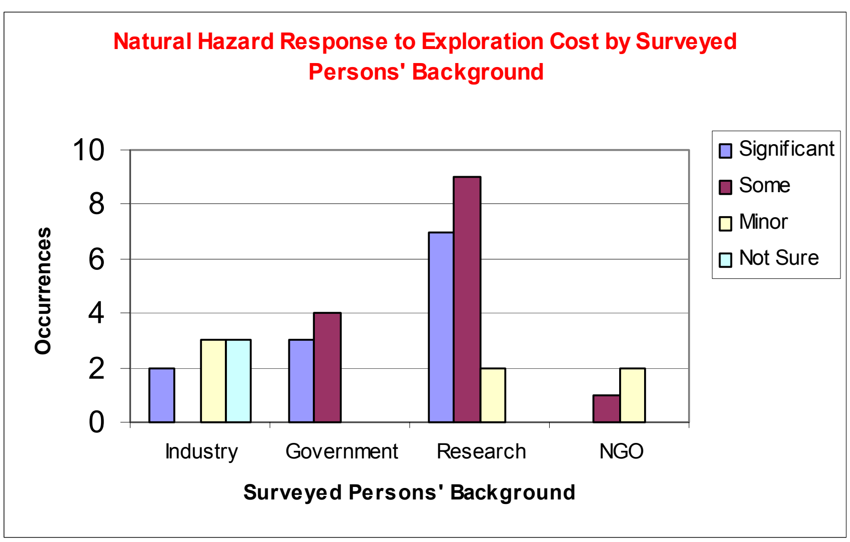


Figure 7.25 Natural Hazard Response to Exploration Cost by Surveyed Persons' Background

Table 7.3.25 Natural Hazard Response to Exploration Cost by Surveyed Persons' Background

	Chi-square test				
	Natural Hazard Response to Exploration Cost by Surveyed Persons' Background				
Performed by					
n	36				
Data Response	**Surveyed Persons' Background**				
	Industry	Government	Research	NGO	**Total**
Significant	2 (2.7)	3 (2.3)	7 (6.0)	0 (1.0)	**12**
Some	0 (3.1)	4 (2.7)	9 (7.0)	1 (1.2)	**14**
Minor	3 (1.6)	0 (1.4)	2 (3.5)	2 (0.6)	**7**
Not Sure	3 (0.7)	0 (0.6)	0 (1.5)	0 (0.3)	**3**
Total	**8**	**7**	**18**	**3**	**36**
X² statistic	23.12				
p	0.0059				

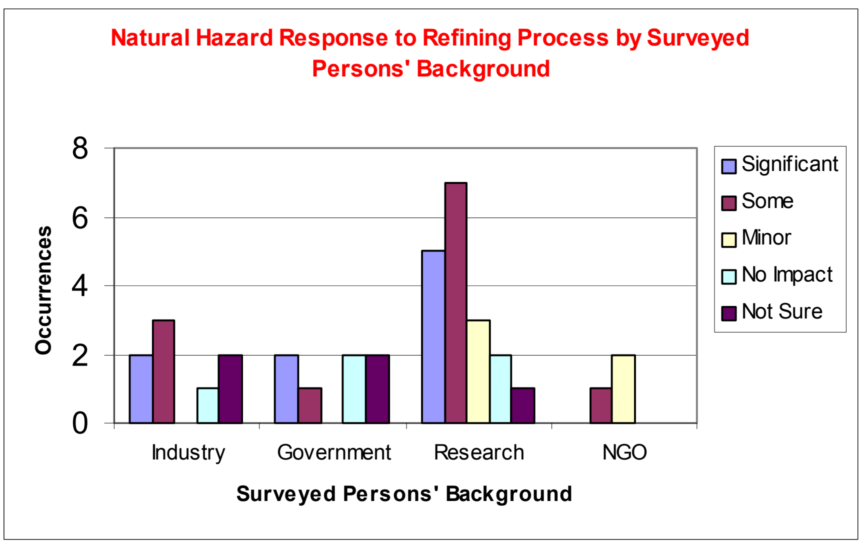


Figure 7.26 Natural Hazard Response to Refining Process by Surveyed Persons' Background

Table 7.3.26 Natural Hazard Response to Refining Process by Surveyed Persons' Background

Test Performed by	Natural Hazard Response to Refining Process by Surveyed Persons' Background				
n	36				
Data Response	Surveyed Persons' Background Industry	Government	Research	NGO	Total
Significant	2 (2.0)	2 (1.8)	5 (4.5)	0 (0.8)	**9**
Some	3 (2.7)	1 (2.3)	7 (6.0)	1 (1.0)	**12**
Minor	0 (1.1)	0 (1.0)	3 (2.5)	2 (0.4)	**5**
No Impact	1 (1.1)	2 (1.0)	2 (2.5)	0 (0.4)	**5**
Not Sure	2 (1.1)	2 (1.0)	1 (2.5)	0 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	14.74				
p	0.2560				

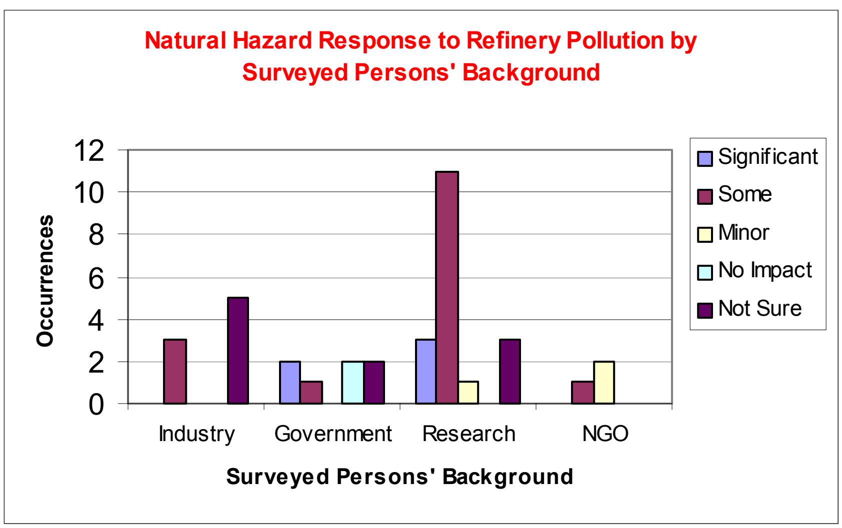


Figure 7.27 Natural Hazard Response to Refinery Pollution by Surveyed Persons' Background

Table 7.3.27 Natural Hazard Response to Refinery Pollution by Surveyed Persons' Background

Test	Chi-square test				
Performed by					
n	36				
Data Response	Surveyed Persons' Background				Total
	Industry	Government	Research	NGO	
Significant	0 (1.1)	2 (1.0)	3 (2.5)	0 (0.4)	**5**
Some	3 (3.6)	1 (3.1)	11 (8.0)	1 (1.3)	**16**
Minor	0 (0.7)	0 (0.6)	1 (1.5)	2 (0.3)	**3**
No Impact	0 (0.4)	2 (0.4)	0 (1.0)	0 (0.2)	**2**
Not Sure	5 (2.2)	2 (1.9)	3 (5.0)	0 (0.8)	**10**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	32.50				
p	0.0012				

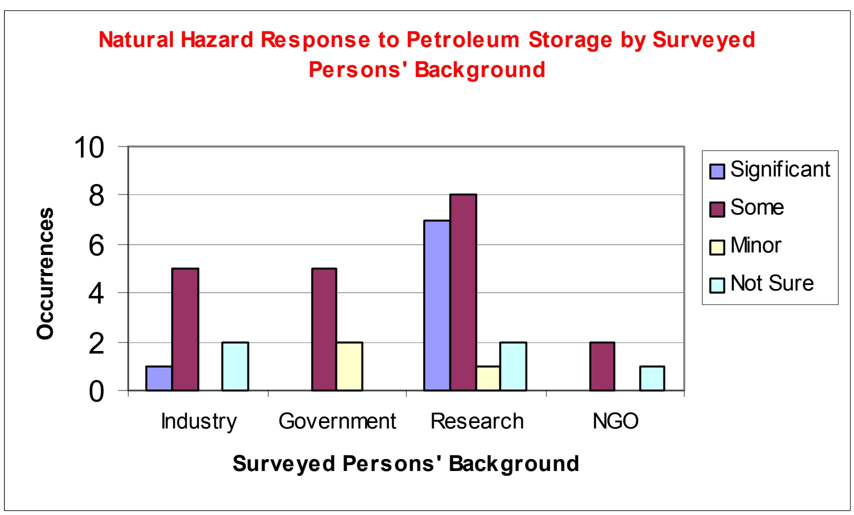


Figure 7.28 Natural Hazard Response to Petroleum Storage by Surveyed Persons' Background

Table 7.3.28 Natural Hazard Response to Petroleum Storage by Surveyed Persons' Background

Test	**Chi-square test**				
	Natural Hazard Response to Petroleum Storage by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	**Surveyed Persons' Background**				
Response	Industry	Government	Research	NGO	**Total**
Significant	1 (1.8)	0 (1.6)	7 (4.0)	0 (0.7)	**8**
Some	5 (4.4)	5 (3.9)	8 (10.0)	2 (1.7)	**20**
Minor	0 (0.7)	2 (0.6)	1 (1.5)	0 (0.3)	**3**
Not Sure	2 (1.1)	0 (1.0)	2 (2.5)	1 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	12.79				
p	0.1723				

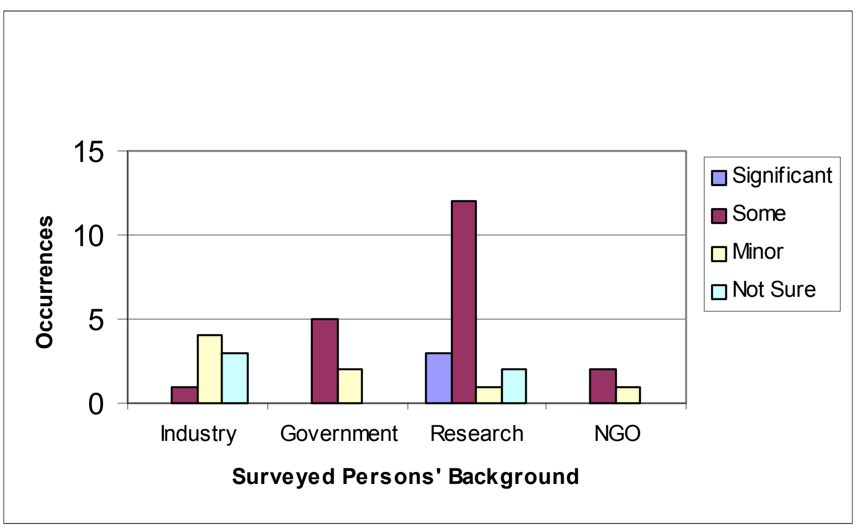


Figure 7.29 Natural Hazard Response to Petroleum Storage Cost by Surveyed Persons' Background

Table 7.3.29 Natural Hazard Response to Petroleum Storage Cost by Surveyed Persons' Background

Test	Chi-square test				
	Natural Hazard Response to Petroleum Storage Cost by Surveyed Persons' Background				
	EVSE, U of Regina				
by					
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	**Total**
Significant	0 (0.7)	0 (0.6)	3 (1.5)	0 (0.3)	**3**
Some	1 (4.4)	5 (3.9)	12 (10.0)	2 (1.7)	**20**
Minor	4 (1.8)	2 (1.6)	1 (4.0)	1 (0.7)	**8**
Not Sure	3 (1.1)	0 (1.0)	2 (2.5)	0 (0.4)	**5**
Total	**8**	**7**	**18**	**3**	**36**
X^2 statistic	16.48				
p	0.0576				

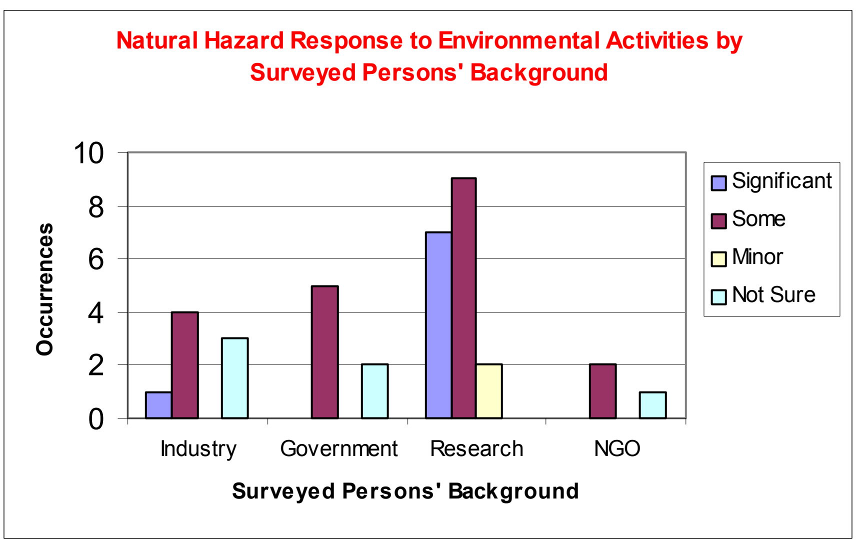


Figure 7.30 Natural Hazard Response to Environmental Activities by Surveyed Persons' Background

Table 7.3.30 Natural Hazard Response to Environmental Activities by Surveyed Persons' Background

Test	Chi-square test				
	Natural Hazard Response to Environmental Activities by Surveyed Persons' Background				
Performed by	EVSE, U of Regina				
n	36				
Data	Surveyed Persons' Background				
Response	Industry	Government	Research	NGO	Total
Significant	1 (1.8)	0 (1.6)	7 (4.0)	0 (0.7)	8
Some	4 (4.4)	5 (3.9)	9 (10.0)	2 (1.7)	20
Minor	0 (0.4)	0 (0.4)	2 (1.0)	0 (0.2)	2
Not Sure	3 (1.3)	2 (1.2)	0 (3.0)	1 (0.5)	6
Total	8	7	18	3	36
X^2 statistic	13.52				
p	0.1405				

7.3.2.The association between the climate change factors and the selection of impacts on petroleum industry processes

The survey and test results of the impacts of climate change factors (temperature, precipitation, humidity, natural hazard) on petroleum industry processes (oil exploration, drilling and production operations, exploration and production infrastructures, transportation activities within exploration and production processes, cost of exploration and production, petroleum refining process, pollutant emission within oil refinery process, petroleum transportation and storage, cost of transportation and storage, environmental management activities in petroleum industry), are described by figures

7.3.31 through 7.3.40 and tables 7.3.31 through 7.3.40.

We can then draw some conclusions from these figures and test results:

1. The increased temperature and changed precipitation tend to have some impacts on oil exploration processes; the changed humidity tends to have minor impacts,

and natural hazard tends to have significant impacts on oil exploration processes. The impacts are strongly related to the climate change factors;

2. The increased temperature and changed precipitation tend to have some or minor impacts on drilling and production operations; the selection of the impacts of changed humidity are different (some, minor, no impact), and natural hazard tends to have significant or some impacts on drilling and production operations. The impacts are strongly related to the climate change factors;
3. The increased temperature and changed precipitation tend to have some impacts, and natural hazard tends to have significant or some impacts on exploration and production infrastructures. The impacts are related to the climate change factors;
4. The increased temperature, changed precipitation and natural hazard tend to have some impacts on transportation activities within exploration and production processes. The impacts are not related to the climate change factors;
5. The increased temperature and changed precipitation tend to have some impacts, and natural hazard tend to have significant or some impacts on cost of exploration and production. The impacts are related to the climate change factors;
6. The increased temperature tends to have minor impacts; the changed precipitation tends to have no impacts; the changed humidity tends to have minor impacts, and the natural hazard tends to have some impacts on petroleum refining process. The impacts are strongly related to the climate change factors;
7. The increased temperature, changed precipitation and natural hazard tend to have some impacts on pollutant emission within oil refinery process. The impacts are not related to the climate change factors;
8. The increased temperature and changed precipitation tend to have some or minor impacts; the changed humidity tends to minor or no impacts, and natural hazard tends to have significant or some impacts on petroleum transportation and storage. The impacts are strongly related to the climate change factors;
9. The increased temperature and natural hazard tend to have some impacts, and the changed precipitation tends to have minor impacts or the impacts are not sure, on petroleum transportation and storage cost. The impacts are related to the climate change factors;
10. The increased temperature, changed precipitation and natural hazard tend to have some impacts on environmental management activities in petroleum industry. The impacts are not related to the climate change factors.

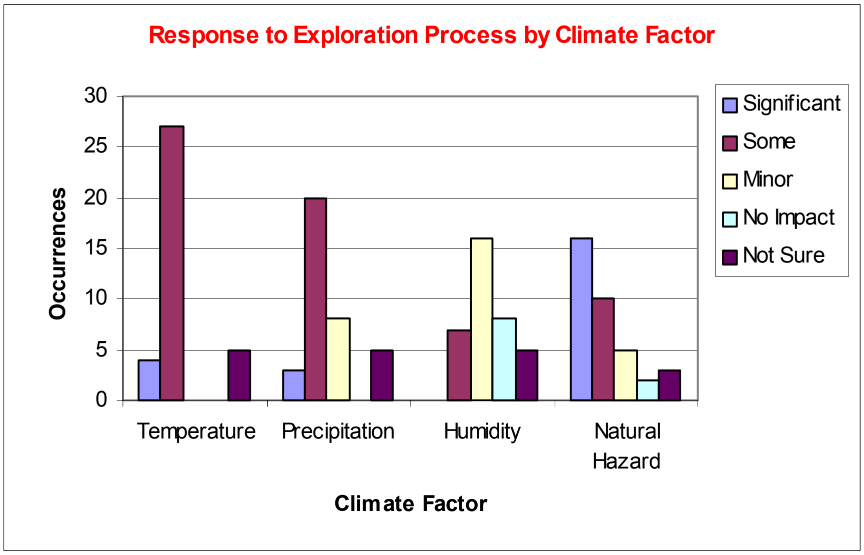


Figure 7.31 Response to Exploration Process by Climate Factor

Table 7.3.31 Response to Exploration Process by Climate Factor

Test	**Chi-square test**				
Performed by	Response to Exploration Process by Climate Factor				
n	144				
Data	**Climate Factor**				
Response	Temperature	Precipitation	Humidity	Natural Hazard	**Total**
Significant	4 (5.8)	3 (5.8)	0 (5.8)	16 (5.8)	**23**
Some	27 (16.0)	20 (16.0)	7 (16.0)	10 (16.0)	**64**
Minor	0 (7.3)	8 (7.3)	16 (7.3)	5 (7.3)	**29**
No Impact	0 (2.5)	0 (2.5)	8 (2.5)	2 (2.5)	**10**
Not Sure	5 (4.5)	5 (4.5)	5 (4.5)	3 (4.5)	**18**
Total	**36**	**36**	**36**	**36**	**144**
X^2 statistic	78.20				
p	<0.0001				

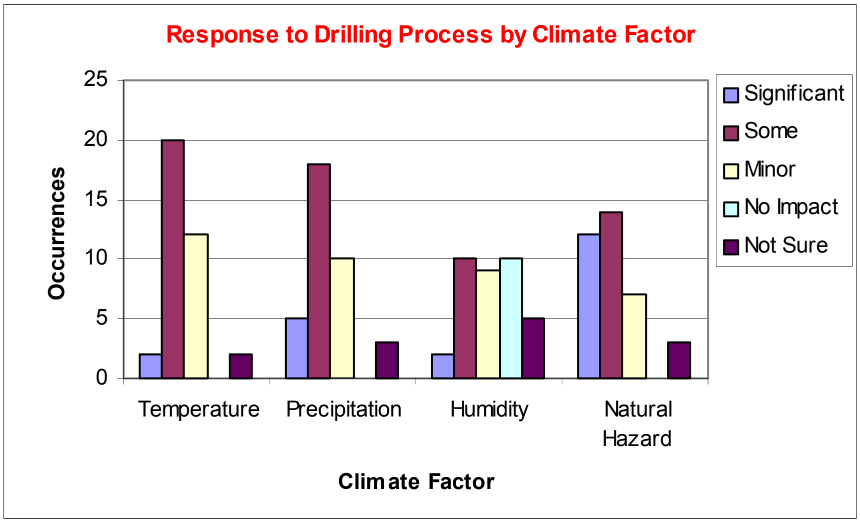


Figure 7.32 Response to Drilling Process by Climate Factor

Table 7.3.32 Response to Drilling Process by Climate Factor

Test	**Chi-square test**				
Performed by	EVSE, U of Regina				
n	144				
Data	**Climate Factor**				
Response	Temperature	Precipitation	Humidity	Natural Hazard	**Total**
Significant	2 (5.3)	5 (5.3)	2 (5.3)	12 (5.3)	**21**
Some	20 (15.5)	18 (15.5)	10 (15.5)	14 (15.5)	**62**
Minor	12 (9.5)	10 (9.5)	9 (9.5)	7 (9.5)	**38**
No Impact	0 (2.5)	0 (2.5)	10 (2.5)	0 (2.5)	**10**
Not Sure	2 (3.3)	3 (3.3)	5 (3.3)	3 (3.3)	**13**
Total	**36**	**36**	**36**	**36**	**144**
X^2 statistic	49.35				
p	<0.0001				

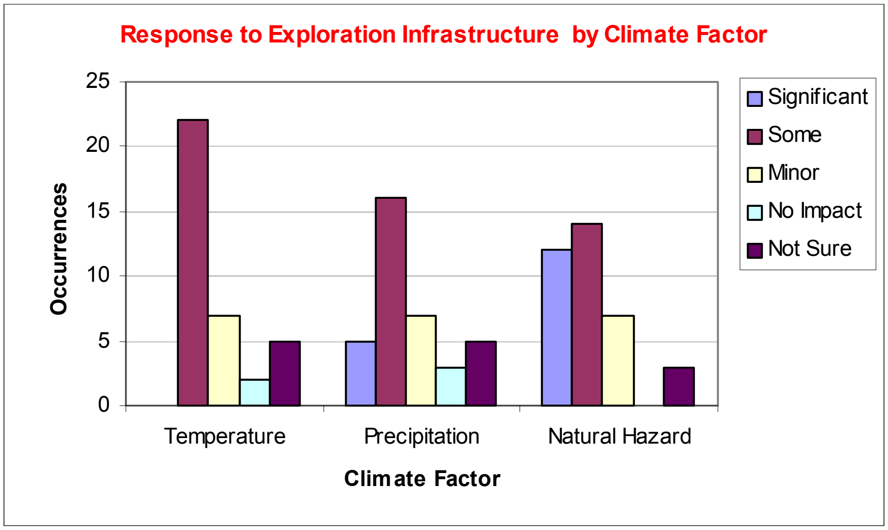


Figure 7.33 Response to Exploration Infrastructure by Climate Factor

Table 7.3.33 Response to Exploration Infrastructure by Climate Factor

Test	Chi-square test			
	Response to Exploration Infrastructure by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data	Climate Factor			
Response	Temperature	Precipitation	Natural Hazard	Total
Significant	0 (5.7)	5 (5.7)	12 (5.7)	**17**
Some	22 (17.3)	16 (17.3)	14 (17.3)	**52**
Minor	7 (7.0)	7 (7.0)	7 (7.0)	**21**
No Impact	2 (1.7)	3 (1.7)	0 (1.7)	**5**
Not Sure	5 (4.3)	5 (4.3)	3 (4.3)	**13**
Total	**36**	**36**	**36**	**108**
X^2 statistic	18.24			
p	0.0195			

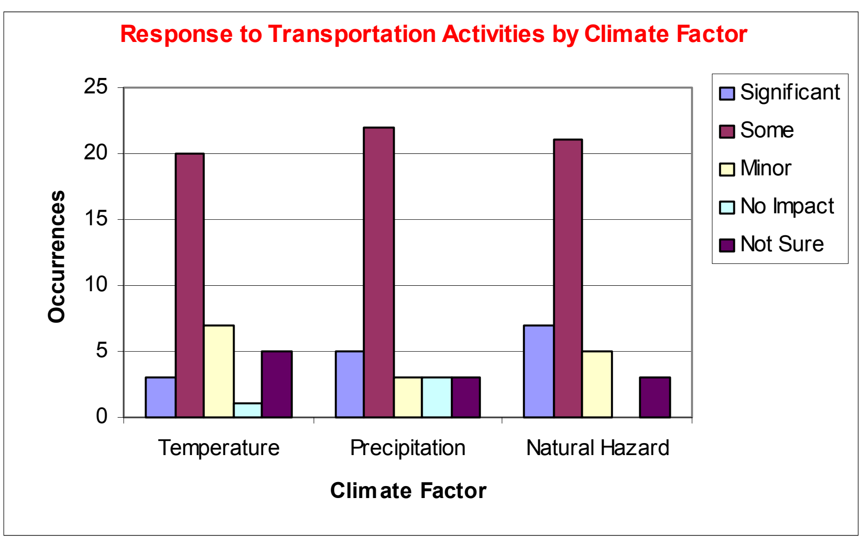


Figure 7.34 Response to Transportation Activities by Climate Factor

Table 7.3.34 Response to Transportation Activities by Climate Factor

Test	Chi-square test			
	Response to Transportation Activities by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data	Climate Factor			
Response	Temperature	Precipitation	Natural Hazard	Total
Significant	3 (5.0)	5 (5.0)	7 (5.0)	**15**
Some	20 (21.0)	22 (21.0)	21 (21.0)	**63**
Minor	7 (5.0)	3 (5.0)	5 (5.0)	**15**
No Impact	1 (1.3)	3 (1.3)	0 (1.3)	**4**
Not Sure	5 (3.7)	3 (3.7)	3 (3.7)	**11**
Total	**36**	**36**	**36**	**108**
X^2 statistic	7.52			
p	0.4814			

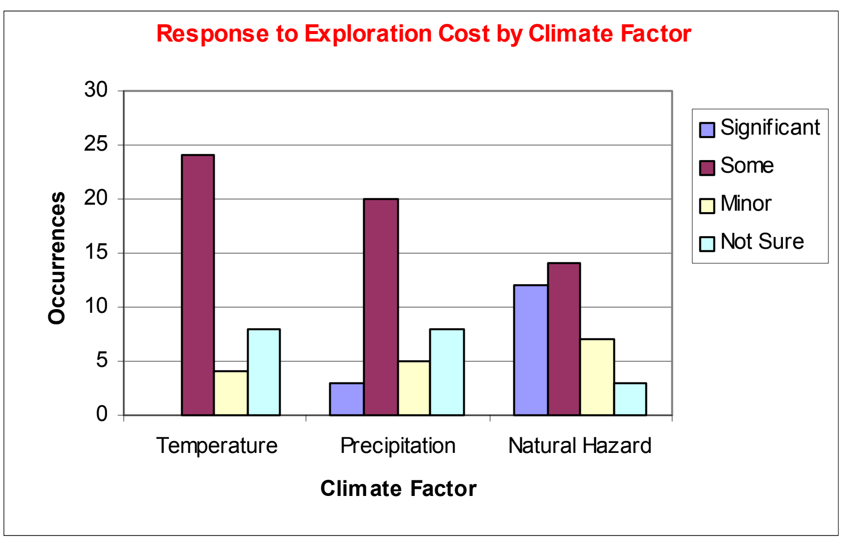


Figure 7.35 Response to Exploration Cost by Climate Factor

Table 7.3.35 Response to Exploration Cost by Climate Factor

Test	**Chi-square test**			
	Response to Exploration Cost by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data		**Climate Factor**		
Response	Temperature	Precipitation	Natural Hazard	**Total**
Significant	0 (5.0)	3 (5.0)	12 (5.0)	**15**
Some	24 (19.3)	20 (19.3)	14 (19.3)	**58**
Minor	4 (5.3)	5 (5.3)	7 (5.3)	**16**
Not Sure	8 (6.3)	8 (6.3)	3 (6.3)	**19**
Total	**36**	**36**	**36**	**108**
X^2 statistic	21.73			
p	0.0014			

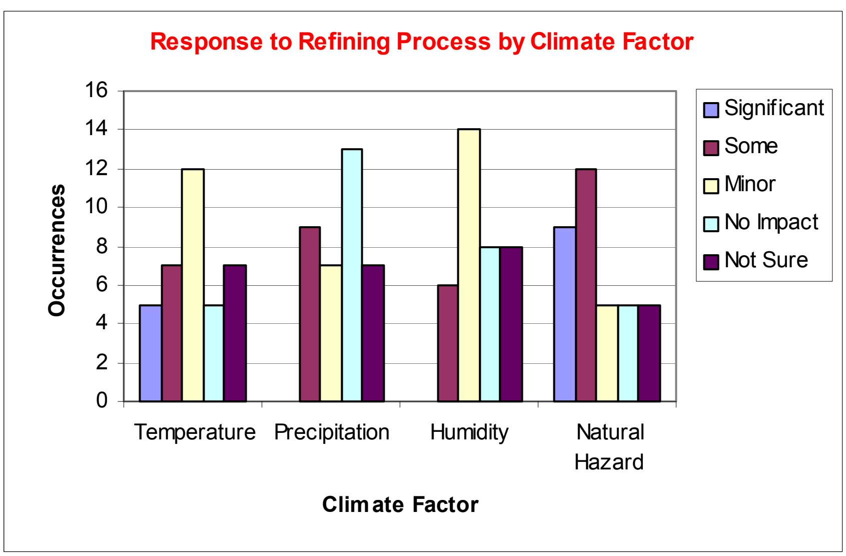


Figure 7.36 Response to Refining Process by Climate Factor

Table 7.3.36 Response to Refining Process by Climate Factor

Test	**Chi-square test**
	Response to Refining Process by Climate Factor
Performed by	EVSE, U of Regina
n	144

Data Response	**Climate Factor** Temperature	Precipitation	Humidity	Natural Hazard	**Total**
Significant	5 (3.5)	0 (3.5)	0 (3.5)	9 (3.5)	**14**
Some	7 (8.5)	9 (8.5)	6 (8.5)	12 (8.5)	**34**
Minor	12 (9.5)	7 (9.5)	14 (9.5)	5 (9.5)	**38**
No Impact	5 (7.8)	13 (7.8)	8 (7.8)	5 (7.8)	**31**
Not Sure	7 (6.8)	7 (6.8)	8 (6.8)	5 (6.8)	**27**
Total	**36**	**36**	**36**	**36**	**144**

X^2 statistic	30.56
p	0.0023

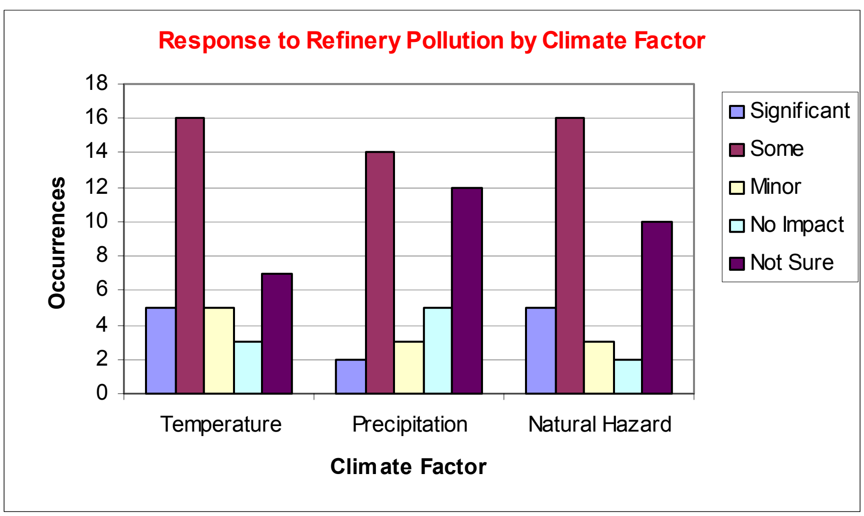


Figure 7.37 Response to Refinery Pollution by Climate Factor

Table 7.3.37 Response to Refinery Pollution by Climate Factor

Test	**Chi-square test**			
	Response to Refinery Pollution by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data	**Climate Factor**			
Response	Temperature	Precipitation	Natural Hazard	**Total**
Significant	5 (4.0)	2 (4.0)	5 (4.0)	**12**
Some	16 (15.3)	14 (15.3)	16 (15.3)	**46**
Minor	5 (3.7)	3 (3.7)	3 (3.7)	**11**
No Impact	3 (3.3)	5 (3.3)	2 (3.3)	**10**
Not Sure	7 (9.7)	12 (9.7)	10 (9.7)	**29**
Total	**36**	**36**	**36**	**108**
X^2 statistic	5.11			
p	0.7456			

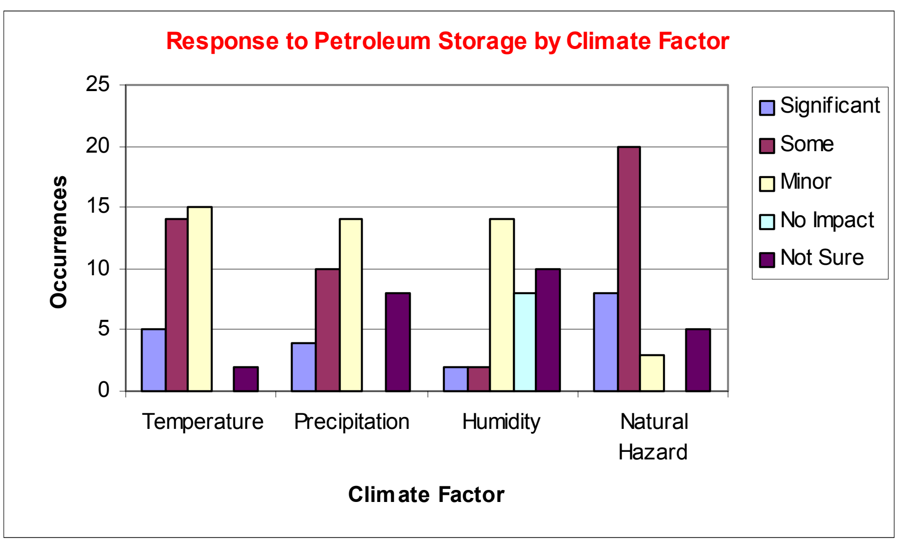


Figure 7.38 Response to Petroleum Storage by Climate Factor

Table 7.3.38 Response to Petroleum Storage by Climate Factor

	Chi-square test				
	Response to Petroleum Storage by Climate Factor				
Performed by	EVSE, U of Regina				
n	144				
Data	**Climate Factor**				
Response	Temperature	Precipitation	Humidity	Natural Hazard	**Total**
Significant	5 (4.8)	4 (4.8)	2 (4.8)	8 (4.8)	**19**
Some	14 (11.5)	10 (11.5)	2 (11.5)	20 (11.5)	**46**
Minor	15 (11.5)	14 (11.5)	14 (11.5)	3 (11.5)	**46**
No Impact	0 (2.0)	0 (2.0)	8 (2.0)	0 (2.0)	**8**
Not Sure	2 (6.3)	8 (6.3)	10 (6.3)	5 (6.3)	**25**
Total	**36**	**36**	**36**	**36**	**144**
X^2 statistic	57.13				
p	<0.0001				

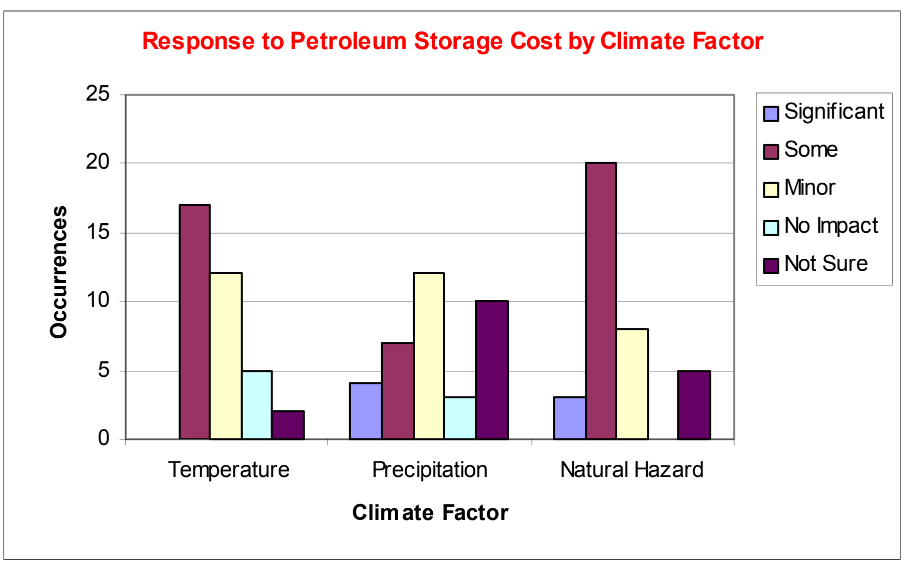


Figure 7.39 Response to Petroleum Storage Cost by Climate Factor

Table 7.3.39 Response to Petroleum Storage Cost by Climate Factor

Test	Chi-square test			
	Response to Petroleum Storage Cost by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data	**Climate Factor**			
Response	Temperature	Precipitation	Natural Hazard	**Total**
Significant	0 (2.3)	4 (2.3)	3 (2.3)	**7**
Some	17 (14.7)	7 (14.7)	20 (14.7)	**44**
Minor	12 (10.7)	12 (10.7)	8 (10.7)	**32**
No Impact	5 (2.7)	3 (2.7)	0 (2.7)	**8**
Not Sure	2 (5.7)	10 (5.7)	5 (5.7)	**17**
Total	**36**	**36**	**36**	**108**
X² statistic	21.55			
p	0.0058			

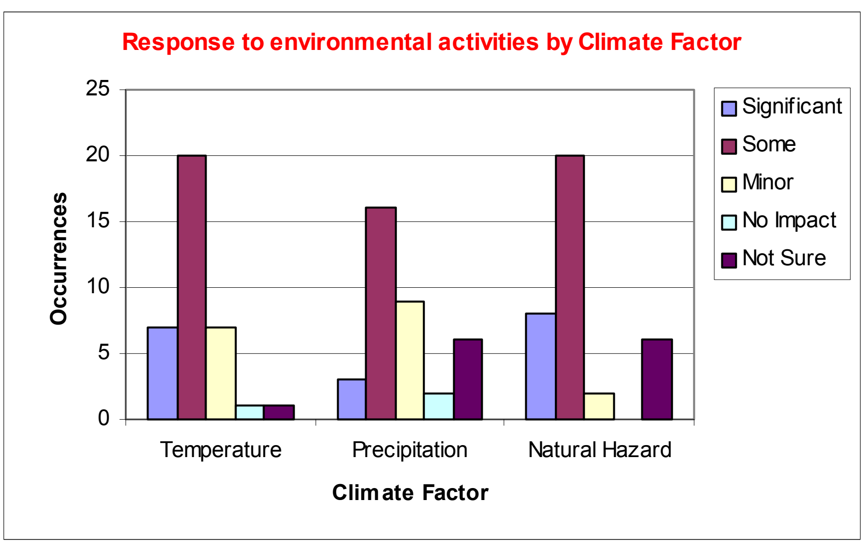


Figure 7.40 Response to Environmental Activities by Climate Factor

Table 7.3.40 Response to Environmental Activities by Climate Factor

	Chi-square test			
	Response to Environmental Activities by Climate Factor			
Performed by	EVSE, U of Regina			
n	108			
Data	**Climate Factor**			
Response	Temperature	Precipitation	Natural Hazard	**Total**
Significant	7 (6.0)	3 (6.0)	8 (6.0)	**18**
Some	20 (18.7)	16 (18.7)	20 (18.7)	**56**
Minor	7 (6.0)	9 (6.0)	2 (6.0)	**18**
No Impact	1 (1.0)	2 (1.0)	0 (1.0)	**3**
Not Sure	1 (4.3)	6 (4.3)	6 (4.3)	**13**
Total	**36**	**36**	**36**	**108**
X^2 statistic	13.08			
p	0.1090			

7.4 DEVELOPMENT OF ASPIC EXPERT SYSTEM

This expert system ASPIC has incorporated the results from the comprehensive questionnaire survey. The SQL query command is constructed according to user selection, which is used to index the database. At last, the system returns the results according to the user's inquiry.

Visual Basic 6.0 is used to develop the main part of this expert system. To consider the integration and convenience, Microsoft ACCESS is selected to develop the database. The information that provided by local experts is divided into two categories, one is stored in database as basic knowledge base, the other part is provided as HTML files which file name is listed in database as index.

The database is organized as four sheets. Three of that act as index table, which is the index of activity, the index of oil process, and the index of weather change. In these index tables, all the impact factors indicated are classified and indexed by integer, which are used in the program to construct the query command. These commands are standard SQL language. The fourth table is the main table, which provided the relationship between the impact factor and the expert answer.

The structure of index table is very simple and is completed with two fields: index and meaning. Index is defined as an integer, which above zero and meaning is defined as a string. Four fields compose the structure of main table: weather change, oil process, activity. Three fields are defined as integer. The other one is answer, which is defined by as a file name.

The statistical results in pre-development period are converted to HTML files. The reason why HTML is introduced is to consider the standard and expansibility. HTML is accepted widely as a standard of document, which is conveniently stored and released. In future version, these results will be generated dynamically to implement this process. HTML is a better selection than others format of document.

This expert system predigests the user selection. The user just needs to select the weather change and oil process that they concerned. More information of petroleum industry and climate-change impacts on environment has been provided as help system to make it convenient to browse related information quickly.

The system is presented in the following figures and tables:

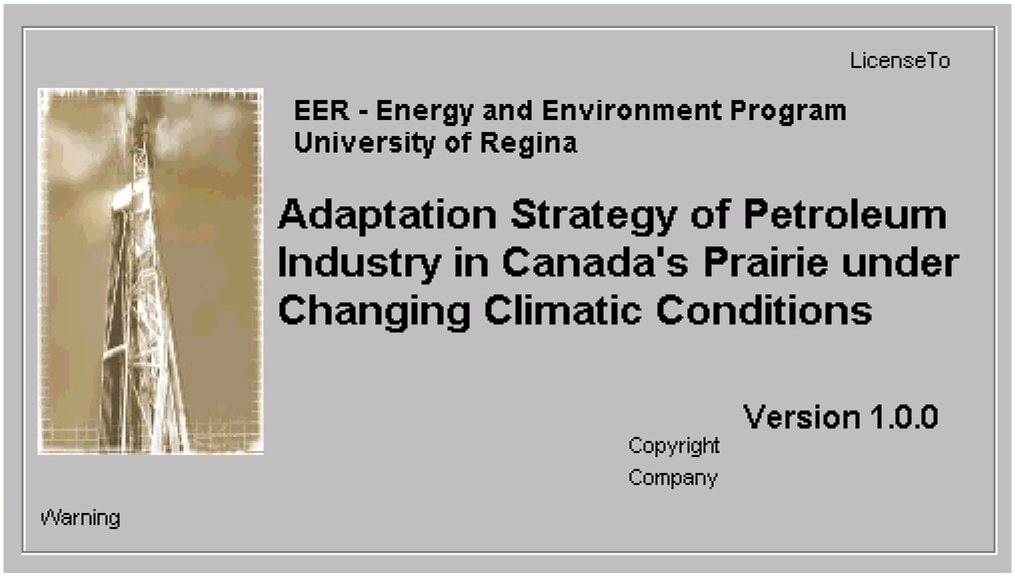


Figure 7.41 ASPIC interface

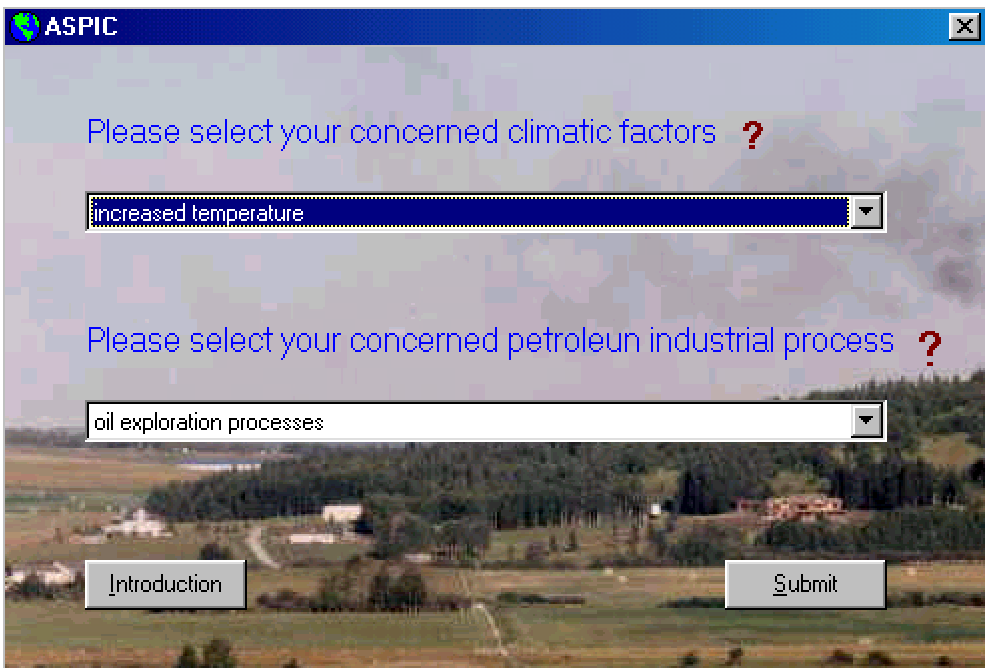


Figure 7.42 User interface

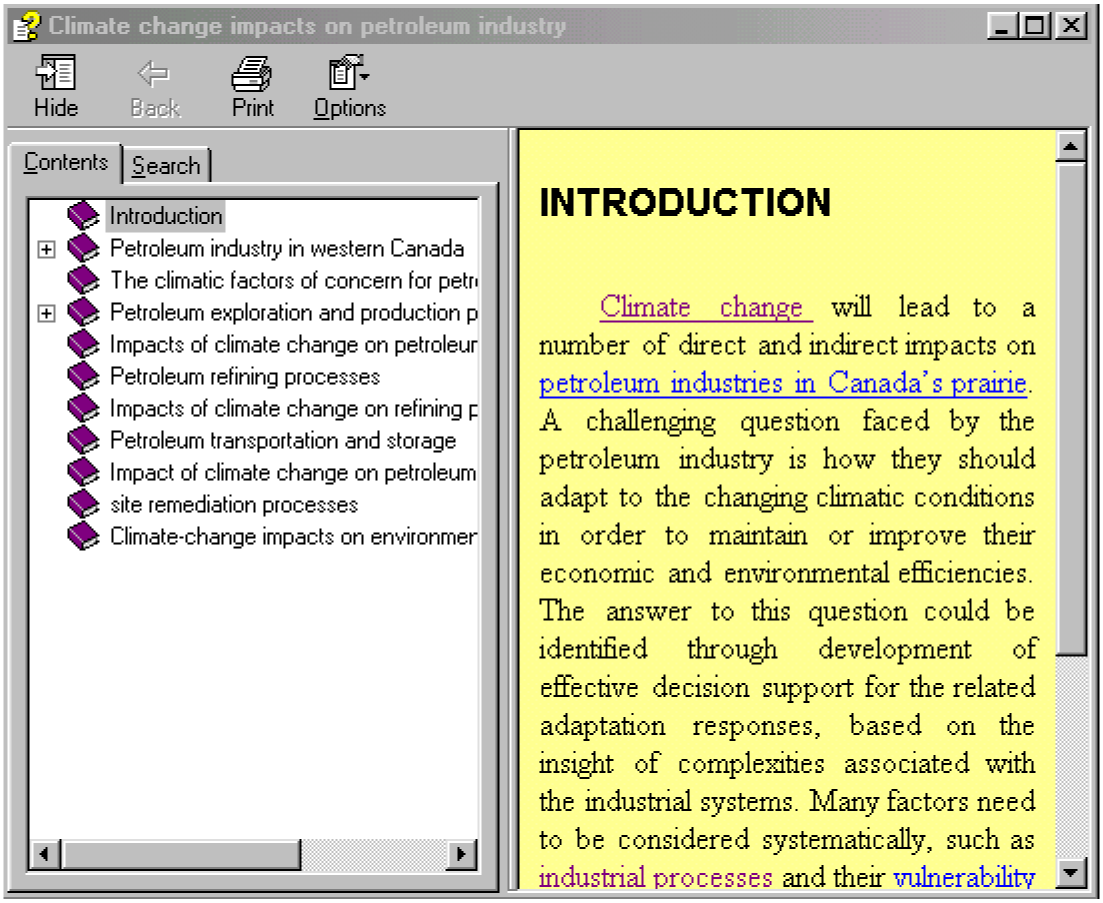


Figure 7.43 System introduction and help system

Example survey result table 1:

	Significant	Some	Minor	No impact	Not sure
number of answers	4	32			6

Example survey table 2:

	Number of answers	Significant	Some	Minor
Do nothing				
Show concerns and be alerted	10		10	
Conduct research to gain insight	8	2	6	
Conduct research and be prepares to take actions	10	2	8	
Begin to take adaptation actions +(c)+(d)	8		8	

Example survey table 3:

	Show concerns and be alerted	Conduct research to gain insight	Conduct research and be prepares to take actions	Begin to take adaptation actions +(c)+(d)
Investigate the condition of related field works under increased temperature	10	8	6	2
Change the timetable of field survey	4	6	2	
Increase the efficiency of field works to shorten the survey period		2	8	4
Develop new technology and survey instruments	2	4	6	2

Example survey table 4:

	Industry	Government	Research organization	Non-governmental organization	Others
Significant			4		
Some	6	6	18	2	
Minor					
No impact					
Not sure	4	2			

7.5. SUMMARY

The industry's perceptions of climate change impacts are important because they influence policy making. Knowledge of the impacts would be helpful for the industries to improve their performance in order to adapt to the changes. In this study, an extensive survey was conducted for industries and governmental organizations. The surveying results were analyzed to identify significant impacts and impact factors.

In general, the respondents were optimistic in their belief that the environment can be improved. They also desired more information about what they as individuals and petroleum industries could do. The petroleum industry should become more active in the related impact and adaptation studies.

8. ADAPTATION STRATEGY OF PETROLEUM INDUSTRIES IN CANADA'S PRAIRIE PROVINCES TO CLIMATE CHANGE

8.1. OVERVIEW

As described in previous chapter of this report, climate change could lead to a number of direct and indirect impacts on petroleum industries in Canada's prairies. With the increased likelihood of climate change resulting from human activities, there is a growing need to collectively understand this process, estimate the magnitude of the changes, determine the impacts on petroleum industries, and identify the most effective strategies for adapting to the anticipated changes induced by climate variability and changes.

This growing need has driven industries to explore creative ways of alleviating this problem with particular emphasis on cooperation across partners and enhancement of petroleum practices. At the current stage, a challenging question faced by the petroleum industries is how they should adapt to the changing climatic conditions in order to maintain or improve their economic and environmental efficiencies. The answer to this question could be examined through adaptation-strategy study for identifying desired alternatives, based on insight of complexities associated with the climatic and industrial systems. Many factors need to be considered systematically, such as industrial processes and their vulnerability to climate change, interactions among different system components, governmental policy adjustments, potential adaptation measures, and inputs from stakeholders (Yin & Cohen 1994; Huang et al. 1996).

Previously, there were many studies of climate-change impacts and the relevant policy responses (Yin and Cohen 1994; Huang et al. 1998; Anderson and DiFrancesco 1998). However, there were very few studies of integrated adaptation within the petroleum sector, leading to lack of effective support for industries and governments to make decisions for relevant actions or policies. Especially, no such research has been reported within the context of Canada's prairie, due mainly to the complexities of this industrial sector, as well as the lack of effective communication between researchers in petroleum-related areas and those of the other areas (e.g. climatological and environmental scientists).

In fact, the system of oil/gas industries is complicated, containing a number of processes and activities that are vulnerable to climate change. These processes and activities are also related to each other, such that a good decision for a process or activity may not be good for the others, and a good plan for a period may not be good for the others (Cohen 1997; Huang et al. 1998). Effective reflection of these complexities is critical for identification of effective adaptation strategies and measures, as well as sound management and control of adaptation processes. Thus, the objectives of this chapter will focus on: (1) design of a rationale framework for integrated studies of adaptation activities within the petroleum sector; (2) classification and analysis of adaptation responses; and (3) examination of governmental adaptation policies and industrial adaptation measures. Interactions among climate change, natural condition variations, industrial activities, environmental concerns, and economic objectives, as well as the related policy implications will be comprehensively considered. It is expected that the effectiveness in adapting to climate change for petroleum industries in Canada's prairie could be improved through implementation of the proposed adaptation strategies.

8.2. PREVIOUS STUDIES

8.2.1. ADAPTATION STUDY METHODS

Previously, there were many studies of climate-change impacts and the relevant policy responses. Adaptation literature includes both adaptation at the individual and the collective scales. Numerous examples of adaptive practices are in the literature (Wheaton and Maciver 1999, IPCC 1997). For example, Yin and Cohen (1994) developed a goal programming approach for assessing climate change impacts and identifying regional policy responses. Koshida et al. (1994) developed GIS-based modeling system in the Canadian study of the Great Lakes – St. Lawrence Basin to examine adaptation responses to the potential impacts of climate change. Holling et al. (1994) developed two simulation models: the South Florida Water Management Model and the Adaptive Environmental Assessment and Management Model, which are used to assess the impacts of alternative adaptation policies on the behavior of the natural ecosystem. In the adaptation study conducted by Kaczmarek et al. (1996), adaptive responses to cope with future water deficits in the Warta River, Poland, were identified as infrastructure development, transfer of water from other river basins, and improved resource management. Smithers and Smit (1997) figured out that adaptation actions that maintain the livelihood of individual farms may not improve the long term adaptation of the regional farming group. Huang et al. (1998) proposed a multiobjective programming method for land resources adaptation planning under changing climate. Anderson and DiFrancesco (1998) studies the potential impacts of climate warming on hydrocarbon production. More studies in this area can be found in Huang et al. (1994, 1996, 1998), and Yin et al. (1994, 1995).

8.2.2. SECTORAL ADAPTATION STUDY

Previously, there were a number of studies focusing on adaptation measures for each sector. As with most of the sectors, many of the water resource adaptation measures are already in force in some capacity, and could be readily applied to the conditions of a changed climate (Wheaton and Maciver 1999; IPCC 1997; Kaczmarek et al. 1996). It is anticipated that there will be growing demand for limited or reduced water resources under a changed climate. Potential adaptations have been identified in both the supply and demand of water resources. One avenue would be to increase the efficiency and coordination of the supply system. On the demand side, much work has been done outlining the possible means for reducing public water use. However, considerable effort will be required to bring about the behavioral changes necessary to alter current patterns of water consumption.

To date, little research has been conducted on measures to reduce the potential impact of climate change on human health (Carter et al., 1994; IPCC 1997). Key areas of interest include the impacts on human health of heat stress, poor air quality and temperature dependent vectors for infectious disease.

Little work has also been done on the potential adaptive responses to the impacts of climate change on regional air issues such as smog, particulate and hazardous air pollutants (Huang et al. 1994 & 1996a). These pollutants have an impact on human health and some of these effects will be exacerbated under a warmer climate. There is also a need to move beyond single-issue management and examine ways to address the suite of regional air issues in an integrated fashion. As further research is conducted on climate change impacts over the next decade, it is anticipated that this type of integrative study will be recognized as more important.

A relatively extensive body of research has been gathered on species protection, although this work has not often been linked to climate change (Holling et al. 1994; IPCC 1997). The majority of protective measures require a high level of management and intervention, the success of which is uncertain since management of natural systems is difficult. In order to develop strategies that are manageable and affordable, this sector will need to explore new and innovative approaches and exercise a substantial degree of coordination. At a minimum, efforts to restore degraded habitats and preserve existing ecosystems should allow for expected changes in climate and the associated effects on the optimum range of species.

Little research has been conducted to date on the specific impacts of climate change on the built environment (IPCC 1997). However, this sector is extremely sensitive to climate, and reducing this sensitivity is a significant research priority. Most of the measures found in the literature have already been tested on actual structures. Therefore, the adjustments required to respond to a changing climate are expected to be manageable. Perhaps the best means of preparing this sector to cope with future climate change is by working to reduce the vulnerability of built structures to the current climate and climate variability by regular reviews of building codes and of the climate information used in their development.

Considerable attention has been paid to the range of adaptive measures employed by industry in responding to the current climate and its associated variability (Smithers and Smit 1997; IPCC 1997). Less work has been done on its potential adaptations to a changed climate. In particular, a host of adaptive mechanisms have been studied for both forestry and agriculture. There were very few studies for identifying adaptation activities within the entire petroleum sector. The adaptive measures in the literature pertaining to industry have, by and large, already been put into practice. This area should be well positioned to cope with the anticipated effects of climate change (Chakma et al. 1989;

Chakma & Islam 1989).

8.3. ADAPTATION STRATEGY STUDY

8.3.1. PRINCIPLE FOR ADAPTATION STUDY

"Adaptation" is commonly defined as the act or process of adapting and the state of being adapted. "Adapt" means to make more suitable, or to fit some purpose, by altering or modifying. The IPCC defines "adaptability" as the "degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate; adaptation can be spontaneous or planned, and can be carried out in response to, or in anticipation of changes in conditions" (Watson et al., 1996).

Why should adaptation to climate change and variability be considered? This is the first question with the start of an adaptation study. Responses to global warming are popularly considered to be mainly in terms of mitigation. However, adaptation is also a main part of the response set. Adaptation is needed for several reasons, principally because human-induced climatic change appears unavoidable regardless of the mitigation action to slow the speed of global warming.

Whether or not a system is affected by a changing climate depends on how sensitive they are to the trigger. The IPCC defines "sensitivity" as the "degree to which a system will respond to a change in climatic conditions (e.g., the extent of change within petroleum sector resulting from a given change in temperature or precipitation)." A main challenge in identifying adaptation strategies is to improve our theoretical understanding and predictive capacity. The purpose of this is to examine adaptation strategies and guide adaptive management. Adaptive management serves to reduce vulnerabilities to, and enhance opportunities of climate variability and change.

The process of adaptation to climate occurs in a wide variety of ways and under many circumstances. The identification of adaptation strategies and measures needs to consider a number of factors and processes, including who or what adapts, what they adapt to, how they adapt and what and how resources are used. For the best and most realistic evaluation of climate problems, adaptation and impacts should be considered together. This joint approach improves the assessment of the significance and dangers of the current and future climate, as well as the determination of solutions (e.g., How to prepare for and adapt to a changing climate) and their priorities. So, the next question at the beginning stage of adaptation study is "to what degree petroleum industries in prairie provinces are vulnerable to the potential effects of climate change?" The degree of vulnerability indicates the amount of adaptation that is required within the context of our history, infrastructure, and technologies.

Characteristics of study sectors related to adaptation include a number of concepts such as resilience, sensitivity, tolerance, thresholds, critical levels, susceptibility, vulnerability, adaptability, adaptive capacity, coping range, flexibility, and different petroleum-related activities. These characteristics, both singly and combined, affect the individual and/or system's adaptability, or adaptive capacity.

Linkage between adaptation and mitigation occur or can occur at both the regional level and at more general decision making levels. Some adaptation options may serve dual purposes by also being mitigation options.

Generally, principles for adaptation studies can be summarized as follows:

- Undertaking adaptation option assessments for adaptation strategy identification;
- Developing detailed practical implementation plans
- Establishing indicators for monitoring their performance;
- Reducing vulnerabilities and enhancing opportunities through implementation of adaptation options;
- Developing and integrating relevant governmental policies for adaptive management;
- Putting sectoral adaptation measures within the scope of national adaptation strategies
- Improving adaptation training facilities, internationally and nationally
- Enhancing communication, education and outreach initiatives.

8.3.2. CHARACTERISTIC OF AN ADAPTIVE PETROLEUM SECTOR

Impact studies under different scenarios suggest that many petroleum activities will be affected by the climate change. In order to help ensure continued development in petroleum industries, it is important to develop effective adaptation strategies. A sustainable and robust petroleum industry means one that is strong and efficient yet preserves the natural environment; it is both productive and resilient; it is one that will be competitive in world markets and will help to sustain the provincial communities and societal structures that are currently enjoyed and valued. Climate directly affects the ability of petroleum industries in prairie provinces to produce goods and services efficiently. As a result, prairie provinces should develop adaptation strategies to reduce the threats and vulnerability of future climate change to the industries.

For the most part, adaptive responses to future climate scenarios have focused on the system's ability and activities to minimize adverse effects. Little attention has been given to the broader scope of adaptation, including identifying opportunities or alleviating problems caused by present conditions such as extreme events or actions that are maladaptive. A theoretical approach to developing adaptation strategies can be followed by applying the characteristics of a good adaptive system to the particular case of a changed climate. The major characteristics of a good adaptive system have been identified as robustness, resilience, and flexibility (Smit 1993):

- *"Robustness"* relates to the ability of the system to withstand disruption caused by an event.
- *"Resilience" is* the "elasticity" of the system in the face of a hazard and its ability to re-establish a state of equilibrium.

- *"Flexibility"* refers to the degree of maneuverability that exists within the system.

8.3.3. CLASSIFICATION OF ADAPTIVE RESPONSES

Coping mechanisms as defined in hazards research can be used to describe categories of adaptive responses. Burton et al. (1993) have described six different coping mechanisms used in response to hazards: *bear the loss, share the cost, modify the events, prevent the effects, change resource use* and *change location.* These could be modified for the purposes of developing adaptive responses to a changing climate. Figure 8.1 shows the six categories of adaptation responses for petroleum industries to adapt to climate change. They are *bear-the-loss, modify-the-event, prevent-the-effects, conduct-research, provide-education* and *avoid-the-impacts.*

"Bear-the-loss" mechanisms take no action to prevent or mitigate or adapt to the impacts of an event, and the resultant losses are borne by the individual industry or shared among petroleum sector. One side-effect of these mechanisms is that they can encourage maladaptive decisions which may reduce a system's stability, resistance, flexibility and robustness. In the long term, the level of effort or cost of adjustment required for these mechanisms is likely to reach a higher price than other responses.

"Modify-the-event" mechanisms take direct action to minimize losses by modifying the event at the outset. Mitigation efforts in limiting greenhouse gas emission from petroleum industries belong to this mechanism.

"Prevent-the-effects" mechanisms make moderate changes in petroleum activities or behavior that minimize or avoid the impacts of an event. These mechanisms promote practices that will likely reduce vulnerabilities to a changing climate. This category is broken down into five sub-categories that address a range of operational adaptation methods:

- *Structural/technological* measures are either physical structures or measures that rely on technological innovation to minimize impacts.
- *Legislative/regulatory/financial* measures are those that require governmental intervention to develop laws, subsidies and incentives, zoning and building codes, and taxes.
- *Institutional/administrative* measures are those that require changes in the structure or function of an institution or administration. These measures may include a range of changes, from policy changes in an existing administration to developing a new institution to regulate activities. They can increase the system's resilience and decrease its vulnerability.

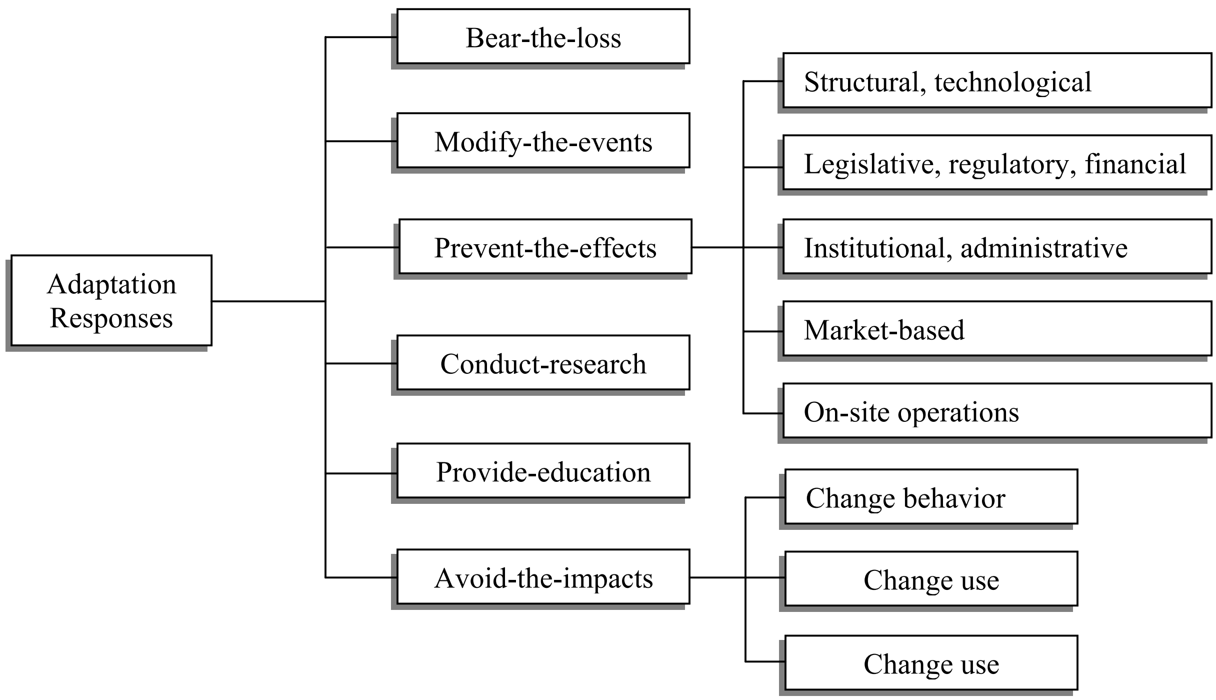


Figure 8.1 Classification of adaptation responses (adapted from Burton et al. 1993)

- *Market-based* measures are activities that attempt to influence the operation of the free market to help adaptation to take place.
- *On-site* operations are actions that deal with the management of resources at the site of operation.

"Research" mechanisms are activities that enhance the understanding of (1) potential impacts and vulnerabilities on petroleum industries created by climate change and variability, (2) adaptive processes, and (3) potential measures to cope with future changes. Research measures often call for more study of impacts and vulnerabilities to future climate or for a strengthening of current petroleum activities to help identify vulnerabilities as they occur. An effective linkage between research activities and policy development is essential to ensure that research planning is productive. If policy institutions fail to identify the information required for improving adaptive responses, researchers cannot undertake the necessary activities to provide the required solutions.

"Education" mechanisms identify both activities that promote understanding of the importance of adaptation and potential adaptation actions that can be undertaken. These mechanisms help distribute adaptation information among the circle of petroleum industrial partners that will enable them to make good adaptive decisions and thereby help them to adopt behavior patterns more attuned to the environment.

"Avoid-the-impacts" mechanisms are typically implemented when it is accepted that impacts exceed the other coping capacities of the system, to the point where major changes are required to avoid a failure. It is recognized that implementing such changes can be very difficult given the short- term costs and, in some cases, the institutional barriers to these major changes. Three types of avoid-the-impacts mechanisms have been identified: *change-behavior, change-use* and *change-location.* These measures respond to an impact by changing behavior patterns or moving the activities to a new location to minimize losses or to look for new opportunities which can be taken advantage of. For instance, this type of response might be especially appropriate for certain northern communities where degradation of permafrost would render infrastructure unusable. In the long term, avoidance is often the most cost-effective means of adapting to a changing climate and can also prompt the development of new opportunities. Unfortunately, the magnitude of the investments required and the possible delays in realizing the benefits of those investments may limit the application of this strategy.

One of the most prudent strategies to adopt today are so-called *no-regrets* strategies. *No-regrets* adaptations are those actions which yield net benefits even in the absence of climate change. There should be potentially an extremely large number of such adaptation actions extending across all activities of the petroleum sector in prairie provinces. The responsibility for such action rests primarily with those who own or manage the resources and economic activities at risk. Governments can encourage and promote assessments of adaptation options, and remove obstacles to such initiatives.

8.3.4. GOVERNMENTAL POLICY ADAPTATION

At this point, there is considerable uncertainty about the potential impacts of climate change and the appropriate measures that should be pursued to adapt to these changes. However these uncertainties do not imply that governments and industry should employ a *wait-and-see* attitude. On the contrary, there are good reasons to believe that forward-looking actions taken now will help us adapt to current climate variability and potential climate change.

Petroleum industries in prairie provinces are affected by a variety of changing factors: population, land-use, global and regional economies, air and water pollution, consumption and technology. Climate change acts in combination with these factors. Moreover, changes in other key variables, such as regional, social, economic, and environmental policies, technology, personal preferences and social values, will influence both the rate of climate change and our ability to adapt to it, as well as identification and implementation of effective adaptation strategies. To reduce petroleum industry's vulnerabilities to climate change and maximize potential benefits, provincial governments play an important role in the identification of adaptation strategies through coordinating and integrating different sectors, making information widely and easily available, as well as having support accessible both organizationally and financially.

In many regions, the economic policies and conditions (e.g., taxes, subsidies, and regulations) that shape private decision making, development strategies, and resource-use patterns (and hence environmental conditions) hinder implementation of adaptation measures. Adaptation and better incorporation of the long-term environmental consequences of resources use can be brought about through a range of approaches, including strengthening legal and institutional frameworks, removing preexisting market distortions (e.g., subsidies), correcting market failures (e.g., failure to reflect environmental damage or resource depletion in princes), and promoting public participation and education. These types of actions would adjust resource-use patterns to current environmental conditions and better prepare systems for potential future changes.

The challenge is to identify opportunities that facilitate sustainable development by making use of existing technologies and developing policies that make climate-sensitive sectors resilient to today's climate variability. This challenge will require industrial partners to have more access to appropriate technologies, information, and adequate financing. Also, adaptation will require anticipation and planning; failure to prepare systems for projected changes in climate means, variability, and extremes could lead to capital-intensive development of infrastructure or technologies that are ill-suited to future conditions, as well as missed opportunities to lower the costs of adaptation. Additional analysis of current vulnerability to today's climate fluctuations and existing coping mechanisms is needed and will offer lessons for the design of effective options for adapting to potential future changes in climate.

The assessment of the overall prairie's capacity for adaptation should not be presumed to be merely the sum of the capacities of each sector. If some sector or geographical area experiences problems adapting to climate change, opportunities exist for relocation or the reallocation of resources into other fields. A coordinated multisectoral plan to deal with climate change will minimize conflicting adaptive strategies and maximize overall benefits for the prairie. Eliminating obstacles and providing direction are the responsibility of both the government and the affected sectors themselves. In order to cooperate with petroleum sector for identifying effective adaptation measure, energy policy and building policy will be the major aspects for governmental policy adaptation.

Energy Policy Adaptation

Seasonal variations in energy demand are influenced by weather and arise from energy needed for heating, cooling and lighting buildings. Numerous studies have shown that the demand for energy is strongly correlated with changes in mean temperature. Climate affects a number of parameters on the energy supply side, including efficiency of thermal generating units and their cooling apparatus, distribution infrastructure and transportation. Climate also has a direct impact on alternative energy sources – wind patterns and cloud cover are important determinants of the feasibility of wind and solar energy, respectively.

Warm weather reduces the efficiency of electrical transmission lines, whereas freezing rain and high winds can damage lines and towers. Lightning strikes can disrupt the distribution of electricity. Freeze-thaw weather cycles can cause problems for electrical supply through falling ice, ice accumulation on overhead conductors and salt deposition. Hot weather can reduce the efficiency of turbine engines used to pump gas in pipelines. On the other hand, frozen ground hinders accessibility to underground portions of the distribution infrastructure and maintenance of underground gas pipelines.

In the prairie provinces, the natural gas and refined petroleum products remain the main sources of energy. Their utilization demand can be highly dependent on climatic conditions through space heating and cooling requirements. The changes in energy demands and costs associated with increased cooling are more difficult to estimate that those associated with decreased heating since heating loads depend strongly on temperature while cooling loads depend on many climatic elements (temperature, humidity, solar radiation, cloud cover, wind). It is difficult to estimate the net changes in many of these elements under climate warming. Furthermore, a strong correlation exists between maximum temperature and peak power consumption. These indicate that while overall demand may decrease, peak power demand may increase, requiring alternation to the structure of the electrical power supply system.

In general, the changing climate may lead to changes in the hydrologic cycle, resulting in more variability in water supply for hydroelectric power production. These losses may be compensated for by an increase in the use of petroleum products, nuclear power and alternative forms of energy.

Other considerations include the vulnerability of pipelines to permafrost degradation, possibly decreased efficiency of thermal generating units and the low capacity of power transmission lines as temperatures rise and transmission losses increase. Furthermore, changes in the frequency of freezing precipitation would have corresponding implications for icing of power transmission lines. Changes in storm frequency could affect the infrastructure that supports the transmission and routing of electricity, causing transmission lines to become less reliable and requiring strengthening of the infrastructure.

In the area of standards and regulations, policy measures that have proved successful in achieving sustained energy savings include the setting of minimum efficiency standards for vehicles, appliances, lighting, boilers, buildings and other equipment. Every region and province must determine for itself the appropriate standards and the future role for such standards. This flexibility is particularly important because various proposals for standards have been made. Some examples of technically achievable performance standards include an increase of automobile fuel efficiency targets, a reduction in average electricity consumption of electrical appliances, and an upgrading of thermal insulation standards.

Regulations are critical in the area of gas and electrical utilities. Governments need to give clear guidelines on how environmental and social costs should be reflected in the planning process, and allow utilities to change business practices so that they can sustain profitability by selling end-use efficiency measures to their customers.

Fiscal and other measures are another important means of removing barriers to cost effective measures for combating climate change. Phasing out subsidies to particular technologies or energy sources is a prerequisite towards achieving market conditions that reflect the environmental hazards of climatic change.

The policies of aid agencies should reflect the need for technological leapfrogging involving the implementation of advanced efficient technologies, for shifting towards program funding as opposed to project support, and for fostering self-reliance through the strengthening of indigenous human resources.

With respect to research and development, governments should enhance and strengthen their support on the capacity of the research and development community to develop alternative energy technologies. To provide society with the technological options it needs to combat climate change, funding for energy research, and especially research directed towards improving efficiency and making renewables cost-effective, needs to be increased and sustained over the long term.

Governments can play a key role in preventing and reducing negative impacts from climate change in the energy sector. Adaptation policies will be most useful in those subsectors likely to incur the greatest negative impacts. Adapted energy policies should encourage people and enterprises to bear additional initial capital costs. If the policies are designed properly and assumptions about climate change impacts turn out to be reasonably correct, bearing these initial capital costs will result in lower overall costs. For example, energy efficiency standards for air conditioners will result in higher initial costs for cooling. The overall life cycle costs, however, should be less than if there were no standards. Such policies are probably best assessed using engineering models, since they involve efficiency improvements.

Adapted energy policies should also involve a more equitable sharing of costs. For example, residential electricity subsidies would tend to hide the true costs of producing electricity. If subsidies are substantial enough, people would have no incentive to restrain their use of electricity for cooling, since other sectors of society are paying for it. Elimination or reduction of subsidies will result in the costs being borne by those responsible for incurring them. Another result of this policy is likely to be greater efficiency. Other, more efficient methods of achieving comfort, such as better building design, use of natural ventilation, and more efficient air conditioners, may be more cost-effective if prices reflect true costs. Subsidies serve to distort markets and eliminate consideration of such options. Pricing and subsidy policies are best analysed using econometric models.

Many systems and policies are not well-adjusted even to today's climate and climate variability. Increasing costs, in terms of human life and capital, from floods, storms, and droughts demonstrate current vulnerability. This situation suggests that there are adaptation options that would make many sectors more resilient to today's conditions and thus would help in adapting to future changes in climate. This options – so-called "win-win" or "no-regrets" options – could have multiple benefits and most likely would prove to be beneficial even in the absence of climate change impacts.

Building Policy Adaptation

The construction of petroleum-related infrastructures needs to be redesigned for weather extremes through use of climatic design values. Whether the costs of coping with factors such as snow and wind loads will increase or decrease remains unclear. As winters become warmer, snow-load requirements will likely decrease in some areas and increase in other, depending on the type of precipitation received (snow or rain).

Climate change will mean a reduced need for winter heating; increased need for summer cooling; and greater possibility of foundation instability from higher winter rainfall, increased frequency of freeze-thaw cycles and drier summers. Since heating, ventilation and air conditioning systems in petroleum-related buildings are sized according to extreme heat, cold and wind, their specifications may need to be re-evaluated to ensure that they continue to perform satisfactorily.

The safety, serviceability and economy of the built environment depends strongly on accurate and realistic predictions of climatic variables, particularly extremes. Even without taking into account the potential trend caused by global warming, long-standing gaps and deficiencies in the determination of climatic design values today prevent optimum decisions from being made now and into the future. For example, good geographic coverage is lacking in some areas and this will worsen if one result of global warming is the relocation of industrial activities to previously less populated areas.

With regard to adapting existing structures to climate change, it is unknown whether the margin of safety built into the National Building Code will be sufficient to maintain safe and economical structures, even with good workmanship and materials. However, in areas where the current code is deficient, those deficiencies could be exacerbated or ameliorated by changes in climate. As a result, climatic design values for national or provincial infrastructure codes and standards will need to be continuously assessed. For example, temperature loads for structures such as railway lines will require review as will snow and wind loads for buildings. Furthermore, return periods for major floods will have to be assessed as a result of increased peak flow in some areas. Safety standards will have to be revised to reflect such changes.

The design life of the structure will also be important in assessing the required changes as a result of climate change. Although roads and buildings can have a physical lifetime of several hundred years when properly maintained, petroleum industrial infrastructure often has relatively short life span because industrial activity and other factors can change significantly within a shorter period. Similarly, different components of structures will display varying sensitivities to climate change. For example, heating, ventilation and cooling systems have a shorter design life than the building they are housed in and can be changed more readily to adapt to a changing climate.

In the prairie provinces, buildings account for more that one-third of all energy used including space and water hearing, lighting, cooling, ventilation and equipment. Buildings can contribute to the mitigation of global warming by becoming more energy-efficient and reducing greenhouse gas outputs. The pursuit of energy efficiency requires increased attention to the construction of durable and healthy building enclosures.

Petroleum-related infrastructure in prairie provinces, both the various buildings and structures, are affected by the frequency, magnitude, and duration of severe and extreme events as well as the cumulative effects from daily climate conditions. The petroleum-related building environment includes exploratory platform, production infrastructure, processing buildings, supporting infrastructure, roads, railways, and engineering structures such as pipelines. Climate change impacts involve changes in construction requirements to deal with an altered climate, changes in the frequency and intensity of floods and other extreme events, and with projected changes in land stability (e.g., landslides and permafrost melting).

- Construction season: the length of the summer construction season is projected to increase while the length of the winter season could decrease. A shortened winter season in north prairie could create difficulty for access due to the decreases in viability of winter roads and for heavy construction due to concerns regarding disturbing sensitive tundra areas with heavy equipment. Thus, construction timetables should be adjusted and re-planned for field implementation.
- Permafrost: increases in frost heave, thaw settlement and slop instability associated with permafrost melting could negatively affect the structural integrity and construction requirements, including utility lines and pipelines. Foundation

conditions are vulnerable in north prairie as permafrost thaws, with differential settlement possibly leading to changes in the integrity of structures, or even collapse of buildings. Utility lines and pipelines may rupture. Exploratory operations might become easier, but waste dumps, tailings dams and water diversion channels could be vulnerable, possibly leading to their collapse and increased and expensive maintenance.

- Building security/integrity: cost savings from decreases in snow loading on buildings and structures are possible in some areas; however, increases in wind and rain loading and in freeze/thaw cycles could have negative impacts. The stability of foundations is of concern in those areas.
- Flooding and other extreme events: particularly vulnerable to changes in extreme events are electricity transmission and utility lines (due to changes in wind and ice loading). Premature structural failure due to deterioration over months and years could be accelerated where increased occurrences of such things as temperature extremes and frequency of combined wind and rain are anticipated.

In many cases, the current margin of safety built into the National Building Code is expected to be sufficient to maintain safe and economical structures, given good workmanship and materials and no significant changes in variability. Adaptation options to address concerns related to structural safety, as well as energy conservation and the minimization of life cycle costs of building and structures, include:

- Upgrading and/or moving of facilities and structures;
- Strengthening of land use planning regulations, particularly in damage-prone areas;
- Revised design criteria and siting where new construction is involved to reflect changing climate conditions;
- Coastal zone management that weighs the relative merits of engineered and natural solution;
- Re-planning and redesigning construction timetables.

8.3.5. ADAPTATION MEASURES FOR PETROLEUM-RELATED ACTIVITIES

Petroleum operations range from exploration to production to transportation, including any associated construction activities - and all are affected by climatic conditions. The climate and related variables of concern for petroleum operations include air temperature, precipitation; wind speed and direction; permafrost depth, extent and degree of ice richness; snow cover depth, extent, and length of season.

As we have seen, many aspects of petroleum industries are sensitive to climate variability and anticipated changes in climate conditions. One way petroleum industries in prairie provinces could lessen the impacts of a changing climate is to reduce known vulnerabilities to current climate variability. In some cases, a changing climate could necessitate additional adaptive actions. Generally, some adaptive strategies for climate-sensitive activities in petroleum industries are suggested below:

- Increased use of energy-efficient cooling technologies and practices would improve the efficiencies of petroleum resources utilization;
- Energy conservation and efficiency measures should be encouraged. Other natural resources, such as wind, solar, and water could be used to increase electricity production;
- Pipeline systems may need to be redesigned to handle greater variability of temperature and precipitation, including a possible increase in the intensity of extreme events. Construction codes and related land-use planning regulations may need to be revised.
- Road weather information systems could be used more widely to optimize winter maintenance operations. Cleaner energy technologies would reduce emissions of pollutants. Increased use of communications technology could reduce the need for travel. More convenient public transit could encourage reductions in automobile usage.
- Reducing emissions (mitigation and minimization) remains the best way to address air issues.

The troubling aspects of global warming issue have been strong enough to prompt the petroleum industries to consider steps that should be taken now to manage the risks posed by potential climate change. Clearly, petroleum sector itself has specific role to play in helping to manage their own activities in a practical and responsible manner, even as the world's governments continue to debate the most effective public policies to pursue. For their part, petroleum companies should work together to help ensure that their operating practices are environmentally sensitive. As their understanding of the potential climate challenge has increased, efforts by the petroleum industries have intensified to develop and incorporate even more sophisticated measures into our operations. Such adaptation actions should be economically prudent with the following characteristics:

(a) Lower energy costs. Oil companies use energy to extract crude oil and natural gas from the ground, refine those raw materials into quality products, and then transport them to retail outlets for purchase by consumers. Like any other business or consumer, they are always looking for ways to reduce energy use and cut costs. Using energy more efficiently, which also reduces or eliminates GHG emissions, just makes good sense - environmentally and economically.

(b) Extend the world's energy resources. Over the decades, oil companies have discovered better ways to produce more useable, saleable products from each barrel of crude oil and cubic foot of natural gas with less waste. Such efforts not only help reduce emissions per unit of product, they also extend the life of energy reserves.

(c) Meet and beat the competition. Oil companies always consider such actions necessary to succeed in a highly competitive market. Oil companies know that their customers are always looking for better lubricating oils, motor fuels and other energy products that will help them operate more efficiently.

(d) Meet rising expectations for new products, new technologies. Petroleum companies, like any other competitive industry, must be constantly developing new products and new technologies to help their customers meet their needs at less cost and greater convenience. Consumers - and state and federal governments - not only expect better quality and more efficient products, but they also require such products to meet or exceed ever-higher standards of environmental performance. Only by developing new products and new technologies can petroleum companies hope to meet the rising expectations of society.

Petroleum companies cannot produce energy products without using energy. Energy runs the engines that keep these companies' production operations moving the drills and pumps at the extraction sites, the boilers in the refineries, the pipeline systems that transport the oil and natural gas to distributors who carry the products by truck, train, or barge to retailers. Petroleum producers must pay for the energy they use; it is a cost of doing business, a large portion of the total cost. Ultimately, petroleum industry based on implementation of adaptation measure could keep operating costs down, while continuing to provide high quality goods and services.

(1) *Adaptive actions for petroleum exploration*

In order to adapt to the changing climatic conditions, the oil and gas industry could respond with new technologies tailored specifically for exploratory drilling in permafrost area. Careful material selection and structure improvement can be considered to resist in the permafrost soil. Efforts should also be made to deal with constraints imposed by permafrost environment in terms of lengthened construction times, abbreviated drilling seasons, and enforced idleness of drilling equipment and support vehicles.

(2) *Adaptive actions for petroleum development and production*

Adaptive actions for petroleum development and production should focus on looking for innovative ways to make their production operations more energy-efficient, less wasteful, and less costly right from the beginning when oil and natural gas are pumped from the ground. A sampling of energy-efficiency efforts by oil and natural gas companies include:

- Using more efficient compressors in drilling operations;
- Connecting oil wells to a production plant's battery re-injection system;
- Using steam produced from highly efficient co-generation plants to assist with recovery of heavy oil (co-generation is an energy-generating process that produces steam and electricity simultaneously);
- Using high-pressure gas feed that is rich in liquids and low in hydrogen sulfide, thus lowering energy input requirements through reduced compression in sour (contains sulfur) gas operations.
- Installing a clean-bum compressor and emission controls on a dehydrator unit and using compressed air-activated, rather than gas-activated, valves;
- Installing high-efficiency compressors and motors, finding and repairing leaks in facilities and processing equipment, installing vapor recovery equipment, and otherwise retrofitting and modifying operations to increase fuel use efficiency;

- Building a gas processing plant, in conjunction with the production facility, and allowing a reduction in flaring;
- Using dual-action pumps at extraction sites to separate the oil and water underground, virtually eliminating gas emissions and reducing the amount of energy used to lift the water from underground; and

Energy-efficiency concerns are leading to other changes in practices at drilling sites. For example, companies are either eliminating or altering the practice of burning off or ***flaring*** the natural gas by-product extracted with crude oil at drilling sites. They originally adopted this practice because the costs of recovering and transporting the gas from remote, isolated areas to distant markets were prohibitive. More recently, however, interest in reducing the waste of a potentially valuable energy commodity - the release of GHGs - and the promise of new energy markets, together with the desire to curb those emissions, have motivated companies to reconsider flaring. Adaptation examples of company initiatives to curb flaring practices include:

- Building a pipeline from an oil production site and transport previously flared natural gas to markets;
- Building a natural gas recovery plant that will capture and process previously flared natural gas;
- Using a flare gas recirculation process at its operation sites;
- Replacing flaring with acid gas injection and, additionally applying new production processes, which have has resulted in previously flared gas being used as fuel;

(3) *Adaptive actions for petroleum refinery process*

Crude oil and natural gas must be refined to provide consumers with usable, high quality energy products. Refining requires energy. Petroleum companies are constantly developing and testing new technologies, equipment and processes that improve the efficiency of their refining operations. Some adaptation measures of individual and collective company initiatives include:

- Increasing the use of natural gas in refining operations, replacing petroleum as the facility's source of energy;
- Using the CO2 recovered from refining operations to carbonate soft drinks;
- Operating co-generation plants to generate electrical energy;
- Recovering and reusing its refineries' expended heat, increasing insulation, reducing processing temperatures;
- Installing a gas compressor in a light oil refinery;
- Replacing gas compressor drivers with electric drivers and replacing gas-driven pumps with more efficient electrical pumps;
- Improving the efficiency of a sulfur recovery facility's production operation;
- In a thermal heavy oil facility, retrofitting treaters with turbolators and replacing electric submersible oil primps with progressive cavity pumps;
- Installing new equipment to recover heat from a reboiler furnace;

- Implementing an on-line energy monitoring system, maximizing energy efficiency controls, and converting fuel gas turbines and pumps to more efficient electrical drives;
- Completing projects that include sulfinol preheat modifications, electrical peak shaving and reducing a plant's inlet pressure drop;
- In a sour gas facility, process changes eliminated the need for compressors;
- Using natural gas to generate electricity and steam (co-generation) which can be sold to a manufacturer of power tools;
- Installing a pre-heating system to improve thermal efficiency and to reduce the use of natural gas; and also, installing more efficient burners that use ultra-low NOx burners and furnaces with exhaust gas recirculation capabilities;
- Installing catalytic converters, lean-burn heads, and air/fuel ratio controllers that help engines in refineries run more efficiently;
- Replacing gas-operated instruments with those fueled by compressed air;
- Developing new technologies that convert coal into clean synthesis gas for use in making electricity, chemicals, fuels and fertilizer.

Through petroleum refinery processes, oil companies continuously seek to improve the combustion efficiency of their gasoline, diesel fuels, and heating oils and to improve lubricant quality to increase their energy output with less waste. Some adaptation activities to develop cleaner fuels include:

- Promoting wider acceptance of diesel engines for offering greater fuel efficiency and, therefore, lower $CO2$ emissions;
- Developing lubricants that improve fuel economy;
- Developing improved ethanol-enhanced gasoline.

(4) ***Adaptive actions for petroleum transportation***

Petroleum producers deliver their products through a series of pipelines, by ship, barge, truck, or railroad. As with other production segments, the most effective adaptation actions should constantly focus on developing ways and means to improve the efficiency of these delivery systems that, in turn, reduce energy use, GHG emissions, and operating costs. A few adaptation measures for industry's delivery operations include:

- Using computerized devices that detect weaknesses in pipeline walls and foundation instability. This early warning system enables industry to correct problems before incidents occur, preventing natural gas leaks and pipeline rupture.
- Installing a flare-reduction and emissions-recovery program in ship and barge loading operations. A unique feature of that system is an oil spray that reclaims the vapors as a product.
- Establishing a new ship-loading process that displaces the gas resting on top of the liquid product and then traps escaping hydrocarbons. The recovered vapors are then recycled into operations.

(5) ***Adaptive measures for common petroleum operation***

Oil and gas industries in prairie provinces are very closely tied to design needs for meeting permafrost characteristics and conditions. Climate change suggests that these areas will experience significant impacts – increased instability of permafrost, and increased flooding, and erosion concerns. Thus there could be significant concerns and cost implications for related petroleum operations.

Altered design practices for all phases of activity generally involve type of materials; wind loading capacity, structure design, routing and sitting. Some adaptation measures corresponding to common oil and gas operation include:

- Steel selection for drilling equipment and pipelines
- Improving engine efficiency of construction and maintenance vehicles
- Improving design and operation of compressor operations
- Design of exploratory and production structures for extreme wind speed and air temperature
- Planning construction timetables for avoiding precipitation effects
- Redesigning construction activities for exploration support, production facilities and pipelines
- Redesigning access to exploratory and production facilities for maintenance under snow covering conditions
- Design and construction of exploratory, production and transportation facilities to adapt to permafrost environment
- Pipeline routing and construction

(6) ***Adaptation measures for infrastructure construction***

Some examples of adaptation measures for infrastructure construction, which may be associated with different petroleum activities, are identified as follows:

- Review construction codes on a regular basis to ensure that they reflect current information on climate change and variability;
- Evaluate whether current safety margins for engineering design such as probable maximum precipitation and snow loads will be sufficient under a changed climate;
- Expand or reinforce riverine flood control systems;
- Strengthen land-use planning regulations to limit development in damage-prone areas;
- Create structures that are more flexible in terms of usage and mobility;
- Alter building and design to reduce cooling requirements.

(7) ***Adaptive Management***

Adaptive management is the practice and implementation of adaptation strategies and measures. There are many ways adaptation can be managed. Types of adaptive management options include structural or infra-structural, legal or legislative, institutional or administrative or organizational, regulatory, educational, financial, incentives or subsidies, research and development, taxes or tariffs or user fees market mechanisms, behavioral and technological changes.

8.4. DISCUSSION

Several common concerns were identified through this adaptation study:

(1) While many adaptation measures have been studied, a comprehensive and coordinated overarching strategy for coping with the impacts of climate change should be considered. It is important that such a strategy be developed in consultation with all affected sectors in order to avoid investment in maladaptive initiatives.
(2) The amount of research on adaptation measures reflects a general level of research conducted on climate change impacts for that particular sector.
(3) When the adaptive measures are put into practice, adjustments may be required for their practical operating procedures. New and innovative approaches will be needed to realize the potential benefits and minimize the impacts of climate change.
(4) Substantial efforts will need to be directed towards technology transfer among industrial partners.

9. CONCLUSIONS

Petroleum operations range from exploration/production and refining to transportation and storage. They are associated with many activities that are vulnerable to climate change. In this study, initial efforts have been made to assess the interrelationships between climate change and petroleum activities in Canada's prairies. Many petroleum-related processes that are vulnerable to climate change are analyzed, the the associated impacts assessed. Perceptions of stakeholders to the climate-change impacts and the related governmental policies were investigated through a number of interactions with the related industrial and governmental personnel. The adaptation strategies within petroleum sector and the related policy adjustments within governmental organizations at different temporal stages and spatial locations were studies, with a number of recommendations provided.

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APPENDIX: Questionnaire Regarding Adaptation Strategy of Petroleum Industries in Canada's Prairie under Changing Climate

Faculty of Engineering

UNIVERSITY OF REGINA

REGINA, SASKATCHEWAN CANADA S4S 0A2

Please provide the following profile information:

Prefix:	Mr.	[ ]
	Ms.	[ ]
Education:	Post-graduate	[ ]
	Undergraduate	[ ]
	Others	[ ]
Age range:	<30	[ ]
	30-40	[ ]
	41-50	[ ]
	>50	[ ]
Company/Institution:	Industry	[ ]
	Government	[ ]
	Research organization	[ ]
	Non-governmental organization	[ ]
	Others	[ ]

************************Please go to the first question, thank you very much********************

(1) Will increased temperature affect oil exploration processes?
(Please choose one)

(f) Significant [ ]
(g) Some [ ]
(h) Minor [ ]
(i) No impact [ ]
(j) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	Positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Site condition	[ ]	[ ]	[ ]
(c) Testing condition	[ ]	[ ]	[ ]
(d) Equipment operation	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(f) Do nothing [ ]
(g) Show concerns and be alerted [ ]
(h) Conduct research to gain insight [ ]
(i) Conduct research and be prepared to take actions [ ]
(j) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate the condition of related field works under increased temperature [ ]
(b) Change the timetable of field survey [ ]
(c) Increase the efficiency of field works to shorten the survey period [ ]
(d) Develop new technology and survey instruments [ ]

(e) Others [ ] Please specify (optional):
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**********************Please go to the next question, thank you very much******************

(2) Will changed precipitation pattern affect petroleum exploration processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Site condition	[ ]	[ ]	[ ]
(c) Testing condition	[ ]	[ ]	[ ]
(d) Equipment operation	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate the changed condition of related field works [ ]
(b) Change the timetable of field survey [ ]
(c) Increase the efficiency of field works to shorten the survey period [ ]
(d) Find new method to make it easier to deliver heavy equipment [ ]
(e) Take actions to protect instruments in the rainy season [ ]
(f) Others [ ] Please specify (optional):
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***********************Please go to the next question, thank you very much*******************

(3) Will changed humidity and cloud patterns affect petroleum exploration processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site condition	[ ]	[ ]	[ ]
(b) Testing condition	[ ]	[ ]	[ ]
(c) Equipment operation	[ ]	[ ]	[ ]
(d) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate the changed condition of related field works [ ]
(b) Change the timetable of field survey [ ]
(c) Increase the efficiency of field works to shorten the survey period [ ]
(d) Take actions to prevent operation instruments from erosion as possible [ ]
(e) Others [ ] Please specify (optional):

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***********************Please go to the next question, thank you very much*******************

(4) Will increased natural hazards affect petroleum exploration processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Site condition	[ ]	[ ]	[ ]
(c) Testing condition	[ ]	[ ]	[ ]
(d) Equipment operation	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate the possible extreme events [ ]
(b) Change the timetable of field survey [ ]
(c) Introduce new instruments which can work under extreme conditions [ ]
(d) Enhance the maintenance of various instruments [ ]
(e) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(5) Will increased temperature affect drilling and production operations? **(Please choose one)**

(a)	Significant	[ ]
(b)	Some	[ ]
(c)	Minor	[ ]
(d)	No impact	[ ]
(e)	Not sure	[ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

		positively affected	negatively affected	both positive and negative
(a)	Site accessibility	[ ]	[ ]	[ ]
(b)	Site condition	[ ]	[ ]	[ ]
(c)	Instruments maintenance	[ ]	[ ]	[ ]
(d)	Equipment operation	[ ]	[ ]	[ ]
(e)	Production amount	[ ]	[ ]	[ ]
(f)	Emission of flared natural gas	[ ]	[ ]	[ ]
(g)	Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a)	Do nothing	[ ]
(b)	Show concerns and be alerted	[ ]
(c)	Conduct research to gain insight	[ ]
(d)	Conduct research and be prepared to take actions	[ ]
(e)	Begin to take adaptation actions + (c) + (d)	[ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a)	Investigate all possible impacts	[ ]
(b)	Change the timetable of drilling and production	[ ]
(c)	Select anti-erosion steel for drilling equipment	[ ]
(d)	Enhance the maintenance of various instruments	[ ]
(e)	Introduce new technique to increase drilling efficiency	[ ]
(f)	Use high-efficiency compressors and motors in drilling operations	[ ]
(g)	Use steam produced from highly efficient co-generation plants to assist with recovery of heavy oil	[ ]
(h)	Install a clean-bum compressor and emission controls on a dehydrator unit and use compressed air-activated, rather than gas-activated, valves	[ ]

(i) Others [ ] Please specify (optional):
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**********************Please go to the next question, thank you very much*******************

(6) Will changed precipitation pattern affect drilling and production operations? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Drilling and production timetable	[ ]	[ ]	[ ]
(c) Instruments maintenance	[ ]	[ ]	[ ]
(d) Equipment selection and operation	[ ]	[ ]	[ ]
(e) Product yield	[ ]	[ ]	[ ]
(f) Emission of flared natural gas	[ ]	[ ]	[ ]
(g) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts [ ]
(b) Change the timetable of drilling and production [ ]
(c) Select anti-erosion steel for drilling equipment [ ]
(d) Enhance the maintenance of various instruments [ ]
(e) Introduce new technique to increase drilling and production efficiency to compensate abbreviated operation seasons [ ]
(f) Use high-efficiency compressors and motors in drilling operations [ ]
(g) Use new technique to replace of heavy-duty mud pump [ ]
(h) Use steam produced from highly efficient co-generation plants to assist [ ] with recovery of heavy oil
(i) Install a clean-bum compressor and emission controls on a dehydrator [ ]

unit and use compressed air-activated, rather than gas-activated, valves
(j) Others [ ] Please specify (optional):

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************************Please go to the next question, thank you very much*********************

(7) Will changed humidity and cloud patterns affect drilling and production operations? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Site condition	[ ]	[ ]	[ ]
(c) Instruments maintenance	[ ]	[ ]	[ ]
(d) Equipment selection and operation	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts [ ]
(b) Select anti-erosion steel for drilling equipment [ ]
(c) Use high-efficiency compressors and motors in drilling operations [ ]
(d) Install a clean-bum compressor and emission controls on a dehydrator unit and use compressed air-activated, rather than gas-activated, valves [ ]
(e) Others [ ] Please specify (optional):

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************************Please go to the next question, thank you very much*********************

(8) Will increased natural hazards affect drilling and production operations? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Site accessibility	[ ]	[ ]	[ ]
(b) Drilling and production timetable	[ ]	[ ]	[ ]
(c) Site condition	[ ]	[ ]	[ ]
(d) Instruments maintenance	[ ]	[ ]	[ ]
(e) Equipment selection and operation	[ ]	[ ]	[ ]
(f) Product yield	[ ]	[ ]	[ ]
(g) Emission of flared natural gas	[ ]	[ ]	[ ]
(h) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional): ______________________________

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible extreme events and their possible impacts [ ]
(b) Change the timetable of drilling and production [ ]
(c) Enhance the maintenance of various instruments [ ]
(d) Upgrade and/or move of facilities and structures, strengthen land use planning regulations, particularly in damage-prone areas, redesign related [ ]

infrastructures
(e) Reinforce flood control system [ ]
(f) Develop storm forecasting system to decrease the storms detriment to drilling and production activities [ ]
(g) Take measures to prevent drilling casing from damage due to permafrost-melting under extreme high temperature [ ]
(h) Others [ ] Please specify (optional):

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************************Please go to the next question, thank you very much********************

(9) Will increased temperature affect exploration and production infrastructures? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Infrastructures structure	[ ]	[ ]	[ ]
(b) Construction timetables for access road, production facilities, and other supporting buildings	[ ]	[ ]	[ ]
(c) Infrastructures foundation stability	[ ]	[ ]	[ ]
(d) Material selection for access-road and field-building constructions	[ ]	[ ]	[ ]
(e) Stability of existing road bases and structures	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures [ ]

(b) Change the timetable of constructions [ ]
(c) Improve the construction efficiency to shorten project period [ ]
(d) Enhance the maintenance of various constructions [ ]
(e) Redesign the foundations and structures to adapt to changed condition [ ]
(f) Redesign pipeline system to handle greater variability of temperature [ ]
(g) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(10) Will changed precipitation pattern affect exploration and production infrastructures? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Infrastructures structure	[ ]	[ ]	[ ]
(b) Construction timetables for access road, production facilities, and other supporting buildings	[ ]	[ ]	[ ]
(c) Infrastructures foundation stability	[ ]	[ ]	[ ]
(d) Material selection for access-road and field-building constructions	[ ]	[ ]	[ ]
(e) Engine efficiency of construction and maintenance vehicles	[ ]	[ ]	[ ]
(f) Stability of existing road bases and structures	[ ]	[ ]	[ ]
(g) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures [ ]
(b) Change the timetable of constructions [ ]
(c) Improve the construction efficiency to shorten project period [ ]
(d) Select anti-erosion material for constructions [ ]
(e) Enhance the maintenance of various constructions [ ]
(f) Redesign the foundations and structures to adapt to changed condition [ ]
(g) Redesign pipeline systems to handle greater variability of precipitation [ ]
(h) Others [ ] Please specify (optional):

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************************Please go to the next question, thank you very much*********************

(11) Will increased natural hazards affect exploration and production infrastructures? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Infrastructures structure	[ ]	[ ]	[ ]
(b) Infrastructures foundation stability	[ ]	[ ]	[ ]
(c) Design life of access road and field building	[ ]	[ ]	[ ]
(d) Building safety	[ ]	[ ]	[ ]
(e) Stability of existing road bases and structures	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures [ ]
(b) Redesign the construction of infrastructures for weather extremes [ ]
(c) Enhance the building security/integrity [ ]
(d) Select anti-erosion material for constructions [ ]
(e) Enhance the maintenance of various constructions [ ]
(f) Redesign pipeline system to handle extreme events [ ]
(g) Others [ ] Please specify (optional): ______________________

***********************Please go to the next question, thank you very much******************

(12) Will increased temperature affect transportation activities within exploration and production processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pipeline rupture and erosion	[ ]	[ ]	[ ]
(b) Pipeline routing and setting	[ ]	[ ]	[ ]
(c) Accessibility to underground portion for maintenance	[ ]	[ ]	[ ]
(d) Efficiencies of turbine engines in pipeline pumping	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional): ______________________

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]

(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and vulnerabilities of related activities, adaptive process, and potential measures [ ]
(b) Select anti-erosion and anti-rupture material for pipeline [ ]
(c) Redesign pipelines routing and enhance the foundation of pipeline to improve its stability [ ]
(d) Introduce new turbine engines to increase efficiencies [ ]
(e) Redesign the ways to access the underground portion for maintenance [ ]
(f) Others [ ] Please specify (optional):

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***********************Please go to the next question, thank you very much*******************

(13) Will changed precipitation pattern affect transportation activities within exploration and production processes? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pipeline rupture and erosion	[ ]	[ ]	[ ]
(b) Pipeline routing and setting	[ ]	[ ]	[ ]
(c) Accessibility to underground portion for maintenance	[ ]	[ ]	[ ]
(d) Efficiencies of turbine engines in pipeline pumping	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]

(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures [ ]
(b) Select anti-erosion and anti-rupture material for pipeline [ ]
(c) Redesign pipeline routing and enhance the foundation of pipeline to improve its stability [ ]
(d) Introduce new turbine engines to increase efficiencies [ ]
(e) Redesign the ways to access the underground portion for maintenance [ ]
(f) Reinforce flood control system [ ]
(g) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(14) Will changed humidity and cloud patterns affect transportation activities within exploration and production processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pipeline rupture and erosion	[ ]	[ ]	[ ]
(b) Efficiencies of turbine engines in pipeline pumping	[ ]	[ ]	[ ]
(c) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]

(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and vulnerabilities of related activities [ ]
(b) Select anti-erosion and anti-rupture material for pipeline [ ]
(c) Introduce new turbine engines to increase efficiencies [ ]
(d) Others [ ] Please specify (optional): ________________________________

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************************Please go to the next question, thank you very much*********************

(15) Will increased natural hazards affect transportation activities within exploration and production processes? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pipeline rupture and erosion	[ ]	[ ]	[ ]
(b) Pipeline routing and setting	[ ]	[ ]	[ ]
(c) Accessibility to underground portion for maintenance	[ ]	[ ]	[ ]
(d) Efficiencies of turbine engines in pipeline pumping	[ ]	[ ]	[ ]
(e) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional): ________________________________

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts and the vulnerabilities of related activities, adaptive process, and potential measures [ ]
(b) Select anti-erosion and anti-rupture material for pipeline [ ]
(c) Redesign pipelines routing and enhance the foundation of pipeline to improve its stability to handler the extreme events [ ]
(d) Redesign the way to access to the underground portion for maintenance [ ]
(e) Reinforce flood control system [ ]
(f) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(16) Will increased temperature affect the cost of exploration and production? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Demand of electricity	[ ]	[ ]	[ ]
(b) Cost of production drilling	[ ]	[ ]	[ ]
(c) Cost of installation of facilities	[ ]	[ ]	[ ]
(d) Cost of on-site drainage system	[ ]	[ ]	[ ]
(e) Cost of maintenance	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Use more efficient compressors [ ]
(c) Use high-pressure gas feed, which is rich in liquids and low in hydrogen sulfide, thus lower energy requirements [ ]
(d) Use dual-action pumps at extraction sites to separate the oil and water from the underground, virtually eliminate gas emissions and reduce the amount of energy used to lift the water from underground [ ]
(e) Find and repair leaks in facilities and processing equipment, install vapor recovery equipment [ ]
(f) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(17) Will changed precipitation patter affect on the cost of exploration and production? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Electricity demand	[ ]	[ ]	[ ]
(b) Cost of production drilling	[ ]	[ ]	[ ]
(c) Cost of installation of facilities	[ ]	[ ]	[ ]
(d) Cost of on-site drainage system	[ ]	[ ]	[ ]
(e) Cost of maintenance	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Use high-pressure gas feed, which is rich in liquids and low in hydrogen sulfide, thus lower energy requirements [ ]
(c) Develop new technique to increase exploration and production efficiency [ ]
(d) Find and repair leaks in facilities and processing equipment, install vapor recovery equipment [ ]
(e) Reinforce the foundation and stability of constructions to reduce the damage [ ]
(f) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(18) Will increased natural hazards affect on the cost of exploration and production? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Electricity demand	[ ]	[ ]	[ ]
(b) Cost of production drilling	[ ]	[ ]	[ ]
(c) Cost of installation of facilities	[ ]	[ ]	[ ]
(d) Cost of on-site drainage system	[ ]	[ ]	[ ]
(e) Cost of maintenance	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Use high-pressure gas feed, which is rich in liquids and low in hydrogen sulfide, thus lower energy requirements [ ]
(c) Develop new technique to increase exploration and production efficiency [ ]
(d) Find and repair leaks in facilities and processing equipment, install vapor recovery equipment [ ]
(e) Reinforce the foundation and stability of constructions to reduce the damage [ ]
(f) Reinforce flood control system
(g) Others [ ] Please specify (optional):
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*************************Please go to the next question, thank you very much*********************

(19) Will increased temperature affect the petroleum refining process? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and alkylation	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Sweetening and treating	[ ]	[ ]	[ ]
(g) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(h) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(i) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(j) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate the technique to prevent oil leakage, spill, and release [ ]
(c) Install automatic monitor system to reduce the fire risk [ ]
(d) Control temperature to prevent thermal cracking within facilities [ ]
(e) Take anti-erosion action to decrease the rates of corrosion of the related facilities [ ]
(f) Find and repair the leakage [ ]
(g) Install oil vapor recovery system [ ]
(h) Others [ ] Please specify (optional):
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**********************Please go to the next question, thank you very much*******************

(20) Will changed precipitation pattern affect the petroleum refining process? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(c) Cracking and isomerization	[ ]	[ ]	[ ]
(d) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(e) Polymerization and alkylation	[ ]	[ ]	[ ]
(f) Sweetening and treating	[ ]	[ ]	[ ]
(g) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(h) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(i) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(j) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):
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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate the technique to prevent oil leakage, spill, and release [ ]
(c) Install automatic monitor system to reduce the fire risk [ ]
(d) Take anti-erosion action to decrease the rates of corrosion for the facilities [ ]
(e) Find and repair the leakage [ ]
(f) Install oil vapor recovery system [ ]
(g) Reinforce flood control system [ ]

(h) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(21) Will changed humidity and cloud patterns affect the petroleum refining process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(b) Cracking and isomerization	[ ]	[ ]	[ ]
(c) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(d) Polymerization and alkylation	[ ]	[ ]	[ ]
(e) Sweetening and treating	[ ]	[ ]	[ ]
(f) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(g) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(h) Pipelines, tanks and auxiliary instruments	[ ]	[ ]	[ ]
(i) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate the technique to prevent oil leakage, spill, and release [ ]
(c) Take anti-erosion action to decrease the rates of corrosion for the facilities [ ]
(d) Find and repair the leakage [ ]

(e) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(22) Will increased natural hazards affect the petroleum refining process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate the technique to prevent oil leakage, spill, and release [ ]
(c) Install automatic monitor system to reduce the fire risk [ ]

(d) Redesign the associated facilities to handle the extreme events [ ]
(e) Take anti-erosion action to decrease the rates of corrosion for the facilities [ ]
(f) Enhance the maintenance, find and repair the leakage [ ]
(g) Enforce flood control system, fire prevent system [ ]
(h) Others [ ] Please specify (optional):

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*************************Please go to the next question, thank you very much*********************

(23) Will increased temperature affect the pollutant emission within oil refinery process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate current techniques to reduce the pollutant emission of each process unit [ ]
(c) Increase the use of natural gas, replacing petroleum as the facility's source of energy [ ]
(d) Use the CO_2 recovered from refining operations to carbonate soft drinks [ ]
(e) Develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, feels and fertilizer [ ]
(f) Install oil vapor recovery system [ ]
(g) Promote wider acceptance of diesel engines for offering greater fuel efficiency to lower CO_2 emissions [ ]
(h) Develop improved ethanol-enhanced gasoline [ ]
(i) Others [ ] Please specify (optional):

**********************Please go to the next question, thank you very much*******************

(24) Will changed precipitation pattern affect the pollutant emission within oil refinery process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Innovate current techniques to reduce the pollutant emission of each process unit [ ]
(c) Increase the use of natural gas, replacing petroleum as the facility's source of energy [ ]
(d) Develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, feels and fertilizer [ ]
(e) Install oil vapor recovery system [ ]
(f) Enhance the maintenance, find and repair the leakage [ ]
(g) Promote wider acceptance of diesel engines for offering greater fuel efficiency to lower CO_2 emissions [ ]
(h) Improve the drainage treatment system to reduce the pollutant emission [ ]
(i) Others [ ] Please specify (optional):

**********************Please go to the next question, thank you very much******************

(25) Will increased natural hazards affect the pollutant emission within oil refinery process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional): ________________________________

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Redesign associated facilities to handle the extreme events, prevent facilities disrupt, crack resulting in pollutant emission [ ]
(c) Redesign pipeline and other auxiliary equipment to prevent leakage [ ]
(d) Change plant location, facilities location to avoid extreme events [ ]
(e) Improve fire alarm and prevent system [ ]
(f) Enhance flood control system [ ]

(g) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(26) Will increased temperature affect the cost of oil refinery process? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Improve fire alarm and prevent system to reduce the damage resulting from fire [ ]
(c) Select new material for facilities and associated constructions to prevent disrupt, oil leakage [ ]
(d) Innovate current technique to reduce oil spill and release [ ]

(e) Install oil vapor recovery system [ ]
(f) Reinforce the maintenance of related facilities [ ]
(g) Others [ ] Please specify (optional):

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************************Please go to the next question, thank you very much*********************

(27) Will changed precipitation pattern affect the cost of oil refinery process? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Improve fire alarm and prevent system to reduce the damage resulting from fire [ ]
(c) Select new material for facilities and associated constructions to prevent disrupt, oil leakage [ ]

(d) Innovate current technique to reduce oil spill and release [ ]
(e) Install oil vapor recovery system [ ]
(f) Reinforce flood control system to reduce the damage resulting from flood [ ]
(g) Reinforce the maintenance of related facilities [ ]
(h) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(28) Will changed humidity and cloud patterns affect the cost of oil refinery process? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Improve fire alarm and prevent system to reduce the damage resulting from fire [ ]
(c) Select new material for facilities and associated constructions to prevent disrupt, [ ]

oil leakage
(d) Innovate current technique to reduce oil spill and release [ ]
(e) Install oil vapor recovery system [ ]
(f) Others [ ] Please specify (optional):

____

**********************Please go to the next question, thank you very much******************

(29) Will increased natural hazards affect the cost of oil refinery process? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Crude oil pretreatment (Desalting)	[ ]	[ ]	[ ]
(b) Crude oil distillation	[ ]	[ ]	[ ]
(c) Solvent extraction and dewaxing	[ ]	[ ]	[ ]
(d) Cracking and isomerization	[ ]	[ ]	[ ]
(e) Catalytic reforming and hydrotreating	[ ]	[ ]	[ ]
(f) Polymerization and alkylation	[ ]	[ ]	[ ]
(g) Sweetening and treating	[ ]	[ ]	[ ]
(h) Unsaturated and saturated gas plant	[ ]	[ ]	[ ]
(i) Asphalt and hydrogen production	[ ]	[ ]	[ ]
(j) Pipelines, tanks and auxiliary instrument	[ ]	[ ]	[ ]
(k) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Improve fire alarm and prevent system to reduce the damage resulting from fire [ ]

(c) Select new material for facilities and associated constructions to prevent disrupt, oil leakage [ ]
(d) Innovate current technique to reduce oil spill and release [ ]
(e) Reinforce flood control system to reduce the damage resulting from fire [ ]
(f) Change behavior, change use and change location to reduce the impacts from extreme events [ ]

(g) Others [ ] Please specify (optional):

**********************Please go to the next question, thank you very much*****************

(30) Will increased temperature affect petroleum transportation and storage? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Accurate measurement of quantities	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline corrosion	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Road and rail tanks	[ ]	[ ]	[ ]
(h) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Use more accurate measurement instruments [ ]
(c) Redesign pipeline to enhance the foundation to improve the stability of pipeline [ ]
(d) Change the timetable of pipeline installation [ ]
(e) Improve the installation efficiency to abbreviate the installation period [ ]
(f) Select new material to prevent corrosion of pipeline [ ]

(g) Improve the stability of pump station operation [ ]
(h) Redesign the foundation of storage tanks [ ]
(i) Strengthen land use planning regulations in damage-prone areas [ ]
(j) Install fire alarm and prevention system [ ]
(k) Use computerized devices to detect weaknesses in pipeline walls and foundation instability [ ]
(l) Redesign tanks to reduce the spill and leakage [ ]
(m) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(31) Will changed precipitation patter affect petroleum transportation and storage? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Accurate measurement of quantities	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline corrosion	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Road and rail tanks	[ ]	[ ]	[ ]
(h) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Invest money to construct additional roads in case of waterways dysfunctional, and road networks are destroyed [ ]
(c) Redesign pipeline to enhance the foundation to improve the stability of pipeline [ ]
(d) Change the timetable of pipeline installation [ ]

(e) Improve the installation efficiency to abbreviate the installation period [ ]
(f) Select new material to prevent corrosion of pipeline [ ]
(g) Improve the stability of pump station operation [ ]
(h) Redesign the foundation of storage tanks [ ]
(i) Reinforce flood control system [ ]
(j) Strengthening of land use planning regulations in damage-prone areas [ ]
(k) Use computerized devices to detect weaknesses in pipeline walls and foundation instability [ ]
(l) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(32) Will changed humidity and cloud patterns affect petroleum transportation and storage? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Accurate measurement of quantities	[ ]	[ ]	[ ]
(b) Pipeline corrosion	[ ]	[ ]	[ ]
(c) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(d) In-land mobile transportation	[ ]	[ ]	[ ]
(e) Road and rail tanks	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Take action to prevent measurement instruments from erosion [ ]
(c) Select new material to prevent corrosion of pipeline [ ]

(d) Install fire alarm and prevention system [ ]
(e) Redesign tanks to reduce the spill and leakage [ ]
(f) Others [ ] Please specify (optional):

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*************************Please go to the next question, thank you very much*********************

(33) Will increased natural hazards affect petroleum transportation and storage? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Accurate measurement of quantities	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline corrosion	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Road and rail tanks	[ ]	[ ]	[ ]
(h) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process, and potential measures [ ]
(b) Redesign pipeline to enhance the foundation to improve the stability of pipeline [ ]
(c) Change the timetable of pipeline installation [ ]

(d) Improve the installation efficiency to abbreviate the installation period [ ]
(e) Improve the stability of pump station operation [ ]
(f) Redesign the foundation of storage tanks [ ]
(g) Strengthen land use planning regulations in damage-prone areas [ ]
(h) Install fire alarm and prevention system [ ]
(i) Redesign tanks to reduce the spill and leakage [ ]
(j) Reinforce flood control system [ ]
(k) Change in-land mobile transportation routes [ ]
(l) Others [ ] Please specify (optional):

____

**********************Please go to the next question, thank you very much*******************

(34) Will increased temperature affect the cost of transportation and storage? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Related instruments maintenance	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline maintenance and repair	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process [ ]

(b) Use computerized devices to supply early warning to correct problems before incidents occur, preventing natural gas leaks and pipeline rupture [ ]
(c) Improve the installation efficiency to abbreviate the installation period [ ]
(d) Realize the automatic control of operation to improve the stability of transportation and storage system [ ]
(e) Install fire alarm and prevention system [ ]
(f) Redesign tanks to reduce the spill and leakage [ ]
(g) Develop new loading process for in-land mobile transportation to prevent hydrocarbon escape [ ]
(h) Change in-land mobile transportation routes [ ]
(i) Install recovery system to recycle vapors back into operations [ ]
(j) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much******************

(35) Will changed precipitation pattern affect the cost of transportation and storage? **(Please choose one)**

____

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Related instruments maintenance	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline maintenance and repair	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process [ ]
(b) Use computerized devices to supply early warning to correct problems before [ ]

incidents occur, preventing natural gas leaks and pipeline rupture
(c) Improve the installation efficiency to abbreviate the installation period [ ]
(d) Realize the automatic control of operation to improve the stability of transportation and storage system [ ]
(e) Redesign tanks to reduce the spill and leakage [ ]
(f) Reinforce flood control system [ ]
(g) Develop new loading process for in-land mobile transportation to prevent hydrocarbon escape [ ]
(h) Change in-land mobile transportation routes [ ]
(i) Install recovery system to recycle vapors back into operations [ ]

(j) Others [ ] Please specify (optional):

************************Please go to the next question, thank you very much********************

(36) Will increased natural hazards affect the cost of transportation and storage? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Related instruments maintenance	[ ]	[ ]	[ ]
(b) Pipeline design and installation	[ ]	[ ]	[ ]
(c) Pipeline maintenance and repair	[ ]	[ ]	[ ]
(d) Pumping stations design, installation and operation	[ ]	[ ]	[ ]
(e) In-land mobile transportation	[ ]	[ ]	[ ]
(f) Storage container installation	[ ]	[ ]	[ ]
(g) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, adaptive process [ ]
(b) Use computerized devices to supply early warning to correct problems before incidents occur, preventing natural gas leaks and pipeline rupture [ ]
(c) Install fire alarm and prevention system [ ]
(d) Redesign tanks to reduce the spill and leakage [ ]
(e) Reinforce flood control system [ ]
(f) Change in-land mobile transportation routes [ ]
(g) Install recovery system to recycle vapors back into operations [ ]
(h) Redesign the foundation of pipelines and storage tanks to handle extreme events [ ]
(i) Others [ ] Please specify (optional):

************************Please go to the next question, thank you very much*******************

(37) Will increased temperature affect environmental management activities in petroleum industry? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pollutant discharge criteria	[ ]	[ ]	[ ]
(b) Pollution control technology	[ ]	[ ]	[ ]
(c) Costs for pollution abatement	[ ]	[ ]	[ ]
(d) Amount of pollutant generated	[ ]	[ ]	[ ]
(e) Pollutant control efficiency	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, update criteria of environmental management [ ]

(b) Innovate current remediation technology, develop new technology [ ]
(c) Take actions to reduce the oil leakage, spill, increase the treatment efficiency to lower the cost for pollution abatement [ ]
(d) Establish new environmental management policy to increase the pollution control efficiency [ ]
(e) Establish special environmental management system for petroleum industry [ ]
(f) Install recovery system to recycle, leakage oil, vapors back into operations [ ]
(g) Implement an on-line energy monitoring system, maximize energy efficiency [ ]
(h) Install a flare-reduction and emissions-recovery program [ ]
(i) Develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, fuels and fertilizer [ ]
(j) Reinforce fire alarm and prevention system [ ]
(k) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(38) Will changed precipitation pattern affect environmental management activities in petroleum industry? (Please choose one)

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pollutant discharge criteria	[ ]	[ ]	[ ]
(b) Pollution control technology	[ ]	[ ]	[ ]
(c) Costs for pollution abatement	[ ]	[ ]	[ ]
(d) Amount of pollutant generated	[ ]	[ ]	[ ]
(e) Pollutant control efficiency	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]
(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, update criteria of environmental management [ ]
(b) Innovate current remediation technology, develop new technology [ ]
(c) Take actions to reduce the oil leakage, spill, increase the treatment efficiency to lower the cost for pollution abatement [ ]
(d) Establish new environmental management policy to increase the pollution control efficiency [ ]
(e) Establish special environmental management system for petroleum industry [ ]
(f) Install recovery system to recycle, leakage oil, vapors back into operations [ ]
(g) Improve drainage system to prevent the pollutant directly moving into ambient [ ]
(h) Implement an on-line energy monitoring system, maximize energy efficiency [ ]
(j) Install a flare-reduction and emissions-recovery program [ ]
(j) Develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, fuels and fertilizer [ ]
(k) Others [ ] Please specify (optional):

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**********************Please go to the next question, thank you very much*******************

(39) Will increased natural hazard affect environmental management activities in petroleum industry? **(Please choose one)**

(a) Significant [ ]
(b) Some [ ]
(c) Minor [ ]
(d) No impact [ ]
(e) Not sure [ ]

If the answer is (a), (b) or (c), please check if the following activities will be affected by climate change?

	positively affected	negatively affected	both positive and negative
(a) Pollutant discharge criteria	[ ]	[ ]	[ ]
(b) Pollution control technology	[ ]	[ ]	[ ]
(c) Costs for pollution abatement	[ ]	[ ]	[ ]
(d) Amount of pollutant generated	[ ]	[ ]	[ ]
(e) Pollutant control efficiency	[ ]	[ ]	[ ]
(f) Others	[ ]	[ ]	[ ]

Please explain more details of the impacts (optional):

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What approach to adapt to the above impacts? (Please choose one)

(a) Do nothing [ ]
(b) Show concerns and be alerted [ ]
(c) Conduct research to gain insight [ ]
(d) Conduct research and be prepared to take actions [ ]

(e) Begin to take adaptation actions + (c) + (d) [ ]

If the answer is (b), (c), (d) or (e), please indicate what detailed actions you would like to recommend:

(a) Investigate all possible impacts, update criteria of environmental management [ ]
(b) Take actions to reduce the oil leakage, spill, increase the treatment efficiency to lower the cost for pollution abatement [ ]
(c) Establish special environmental management system for petroleum industry [ ]
(d) Install recovery system to recycle, leakage oil, vapors back into operations [ ]
(e) Improve drainage system to prevent the pollutant directly moving into ambient [ ]
(f) Implement an on-line energy monitoring system, maximize energy efficiency [ ]
(g) Install a flare-reduction and emissions-recovery program [ ]
(h) Reinforce fire alarm and prevention system [ ]
(i) Develop new technologies to convert coal into clean synthesis gas for use in making electricity, chemicals, fuels and fertilizer [ ]
(j) Others [ ] Please specify (optional):

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***********************************The end, thank you very much**************************