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Cost-Benefit Analysis Case Study on Regulations to Lower the Level of Sulphur in Gasoline

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Abstract

The Canadian Cost-Benefit Analysis Guide: Regulatory Proposals, sets out the general methodology and analytical steps to perform a cost-benefit analysis of proposed regulatory changes. To make the Guide operational, this case study has been prepared following the analytical approach recommended by the Guide. In 1994 the sulphur content of Canadian gasoline was found to be high and varied widely across the country. Scientists and health experts have found evidence that emissions of pollutants from vehicles cause considerable harm to the health of Canadians and to the environment. In order to derive the net economic benefits, we integrate the economic benefits with the economic costs for each of the alternative scenarios. In the cost-benefit analysis, all private costs must be measured in terms of their economic opportunity costs. The results indicate that reducing the sulphur in gasoline for any scenario under consideration would generate substantial net health benefits or well-being for Canadians as a whole. Estimates of the net present value (at an eight percent discount rate) range from $1,809 million to $2,663 million.

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Table of Contents

EXECUTIVE SUMMARY

I. Introduction

The Canadian Regulatory Analysis Guide lays out the general methodology and analytical steps to perform a cost-benefit analysis of proposed regulatory changes. To make the Guide operational, this case study has been prepared following the analytical approach recommended by the Guide. The case study first identifies the alternative options and then a cost-benefit analysis is carried out to evaluate the alternatives. The report also provides a summary table to present the main findings of the analysis.

II. Identification of Policy Issues

In 1994 the sulphur content of Canadian gasoline was found to be high and varied widely across the country. Scientists and health experts have found evidence that emissions of pollutants from vehicles cause considerable harm to the health of Canadians and to the environment. In addition, high sulphur fuels hinder the development of more fuel efficient motor vehicles needed for the future control of greenhouse gas emissions.

III. Developing Alternative Scenarios

The objective was to constrain the national sulphur level in gasoline so that from January 1, 2001 it would never be higher than the national average in 1997. Alternative scenarios are developed in terms of the sulphur concentration, and their incremental benefits and costs are measured as compared with the "without regulation" or base case scenario. The base case is established with the level of sulphur maintained at 410 ppm over the study period from 2001 to 2020. The alternative six scenarios represent a scale of increasingly restrictive sulphur-in-gasoline regulations. These scenarios are summarized in Table 1.

Table 1
Alternative Scenarios

Sulphur Concentration	Scenario					
	1	2	3	4	5	6
Max. Annual Average (ppm)	360	250	200	150	100	30
Never-to-exceed (ppm)	420	300	250	200	150	80

IV. Assessing Benefits and Costs of Alternative Options

The incremental annual benefits and costs of alternative options in excess of the baseline scenario are estimated.

4.1 Measurement of Costs

The costs are the outlays made to purchase the resources used to implement the regulatory option. They include the compliance costs incurred by suppliers of fuels and the administrative costs incurred by government. There are 17 refineries that produce fuels in Canada. The total capital investment for each of the six scenarios is assumed to be incurred in 2000. Annual operating costs are incurred, beginning in 2001. In order to enforce the regulations, governments are expected to incur some additional administrative costs. These costs should be all counted as part of the economic cost for each of the alternative scenarios.

4.2 Measurement of Benefits

The basic methodology used in quantifying the benefits is the damage function approach that provides the scientific assessment of the impacts of varying levels of sulphur in gasoline on ambient air pollution concentrations, which, in turn, affects the environment and human health. For each of the alternative scenarios, the measurement of the benefits is carried out in four stages:

- the change in vehicle emissions caused by changes in the level of sulphur in gasoline;
- the change in ambient air quality affected by changes in emitted pollutants by vehicles;
- the impact on environment and human health by changes in ambient air quality; and
- the assessment of the impact on environment and health in monetary value.

4.2.1 Reductions in Sulphate Concentrations

The ambient air model estimates the changes in emitted particles and gases resulting from reduction of specific level of sulphur. The focus of the analysis will be on seven cities across the country. The cities are Vancouver, Edmonton, Winnipeg, Toronto, Montreal, Saint John, and Halifax. The results are then extrapolated to the nation as a whole.

According to health experts, the most appropriate way to address atmospheric changes is to select a pollutant for which significant change can be projected and for which a sufficient health impact database also exists in literature. Sulphate is selected as the best index of the mixture.

4.2.2 Impact on Health and Environment

The functional relationship between ambient air pollution concentration and a number of human health responses has to be established from the epidemiologic research and quantified. For each concentration response relationship, the estimate selected from the middle of the range reported in various studies is considered as the most likely results of that health effect. There is however a selected range of low and high estimates based on the variation in results across the studies to account for uncertainty. Each of the low, central, and high estimates is assigned a probability weight. These probability weights are combined with the low, central, and high estimates to create a probability distribution of expected total health benefits.

With the sulphur concentration reductions for each of the alternative scenarios, the health concentration-response and characteristics of seven selected cities, one can estimate each of the health outcomes of all seven cities for each of the six scenarios. To measure the national impact of changes in sulphur levels in fuels on human health, the effects have to be adjusted upward.

4.2.3 Valuation of Health Effects in Monetary Terms

The approach used to value the health impacts in monetary terms is the benefit transfer method that relies on information available from existing studies in the U.S. and Canada that is adjusted to fit the circumstances of this case. The fundamental principle to measure various health effects is the willingness to pay (WTP) principle. While WTP estimates are not available for health effects, cost-of-illness estimates are used and adjusted to reflect the economic or social benefits of reduced morbidity.

For example, one of the key impacts in lowering the level of sulphur in gasoline is to reduce the risk of premature death. The benefits of these risk reductions can be estimated in terms of the value of statistical lives (VSL). It is a measure derived from the aggregation of many small risks over an exposed population.

With the multiplication of the central estimates of the monetary valuation for each of the health effects and the annual frequency of the corresponding occurrences, we can obtain the annual monetary value of the avoided health effects over the 20-year study period.

4.3 Net Health Benefits for Canada

In order to derive the net economic benefits, we integrate the gross benefits with the incremental costs for each of the alternative scenarios. In the cost-benefit analysis, all private costs must be measured in terms of their economic opportunity costs. The annual net benefits can be estimated over the 20-year period and discounted by the economic opportunity cost of capital in order to derive the net present value of each of the six alternative scenarios under consideration.

Using the 8 percent economic discount rate, the results as shown in Table 2 indicate that reducing sulphur in gasoline for any scenario under consideration would generate substantial net health benefits or well-being for Canadians as a whole, ranging from $1,809 million to $2,663 million.

Table 2
Net Economic Benefits for Alternative Scenarios
(millions of 2000 prices)

Scenarios	Net Present Value @8%
Scenario 1: 360 ppm	1,809.2
Scenario 2: 250 ppm	2,104.4
Scenario 3: 200 ppm	2,416.9
Scenario 4: 150 ppm	2,576.4
Scenario 5: 100 ppm	2,663.1
Scenario 6: 30 ppm	2,414.1

4.4 Dealing with Uncertainty and Risk

Sensitivity analysis is conducted to identify variables that may have a major impact on the net benefits of the regulations. The risk variables selected for this case study include the capital costs of retrofitting the refineries, the changes in operating costs due to the production of low sulphur in gasoline, the response of premature mortality to sulphate concentrations, and the value of a statistical life.

Monte Carlo simulations are used in which the values of uncertain variables are selected according to the ranges of their possible values and the specified probability distributions. The expected value of the net present value of net benefits for each scenario is very close to the value of the respective determinate cases. For example, the expected net benefits for scenario 6 for 10,000 runs range from $137.2 million to $5,410.9 million. This implies there is zero probability of getting the negative net benefit.

Several items of health and environmental effects are not quantified. First, the impacts of pollutants other than sulphate on air are not accounted for. Second, the impact of the long-range transport of air pollution is not taken into account. Third, the impacts on agriculture, forest and fishing are not properly assessed and quantified. Fourth, potential visibility changes are not assessed. Fifth, the positive impacts on controlling greenhouse gas emissions are not accounted for.

4.5 Impacts on Stakeholders

A stakeholder analysis is conducted to identify the impact of the regulations on specific groups in society and to examine how much they would gain or lose as a result of the implementation of the regulations. In this case, the stakeholders will include oil refineries that have to comply with the regulations, refinery workers who are laid off, individuals and households who will receive benefits because of avoided health effects, and provincial governments who are responsible for the health systems and financing the public health of their respective provinces in Canada and the federal government who is responsible for monitoring and enforcing the regulations.

Individual Canadians are the recipients of most of the benefits in all the scenarios. Provincial governments also benefit a small amount because of the reduction of the number of hospital admissions and other associated costs. The shareholders of the companies owning the refineries bear part of the costs of complying with the regulations. A significant amount of the costs would be passed forward to consumers in terms of higher prices of gasoline, but these costs are relatively small as compared to the overall health benefits received by individual Canadians. Finally, there are some economic costs of adjustment suffered by the laid off workers as a result of refinery closures.

4.6 Conclusion

Reductions of sulphur in gasoline for all of the six alternative scenarios will generate a substantial amount of health benefits to Canadians, ranging from $1.8 billion to $2.7 billion in 2000 prices. The risk analysis also suggests that there is zero probability of getting a negative economic benefit. The stakeholder analysis indicates that the Canadian refiners can pass a significant amount of costs forward to final consumers, hence, their competitiveness should not be significantly affected.

The most stringent scenario 6 of lowering sulphur in gasoline to 30 ppm would generate economic benefits of $2.4 billion in 2000 prices. It may not be the scenario with the largest amount of benefits. However, it is the scenario that will create a suitable regulatory environment because it would generate not only a considerable amount of benefits but also help the development of more fuel efficient motor vehicles needed for the control of greenhouse gas emissions in the future.

Cost-Benefit Analysis Case Study on Regulations to Lower the Level of Sulphur in Gasoline

I. Introduction

An updated Canadian Regulatory Analysis Guide was drafted in 2006 for the Government of Canada.[1] The Guide provides the general methodology and analytical steps to perform a cost-benefit analysis of the regulatory options. To make the Guide operational, this case study has been prepared following the analytical approach recommended by the Guide. The case study first identifies the alternative options and then a cost-benefit analysis is carried out to evaluate the alternatives.

One of the key objectives for undertaking this case study is to illustrate to practitioners the type and level of analysis that is appropriate for the appraisal of such a regulation. It also provides a summary table to present the main findings of the analysis in a transparent manner.

The development of this regulation was initiated in November 1994 when the Canadian Council of Ministers of the Environment (CCME) established the Task Force on Cleaner Vehicles and Fuels. Its mandate was to develop alternative options and recommendations on a national approach to new vehicle emissions, efficiency standards and fuel formations for Canada. A year later, the Task Force recommended that Environment Canada consult with the stakeholders affected by a decision to set a cost-effective limit for sulphur in gasoline.[2] Subsequently, from 1996 to 1998 a multi-stakeholder steering committee was set up to undertake in-depth studies by three expert panels that eventually led to the decision to implement the regulations.[3] These three expert panels were Atmospheric Science Panel, Health and Environment Panel, and Costs and Competitiveness Panel. The

[1] Privy Council Office, Government of Canada, *Canadian Regulatory Analysis Guide*, (March 2006).
[2] Canada Gazette Part I, *Sulphur in Gasoline Regulations*, (October 31, 1998).
[3] The multi-stakeholder steering committee consists of representatives from the petroleum refining and automotive industry associations, federal departments of Health Canada, Environment Canada, Industry Canada, Transport Canada, and Natural Resources Canada, one environmental group, and several provinces.

present document is prepared based on the assessment and research carried out at that time by this joint industry and government effort.

II. Identification of Policy Issues

In 1994 the sulphur content of Canadian gasoline was found to be high and varied widely across the country.[4] The volume of sulphur emission from gasoline was highest in the urban areas of the country. The average sulphur level in Canada also increased over time. As of 1996, although Canada had lower sulphur levels than Latin American countries, the level was higher than most developed countries including the United States, Europe, and Australia.

Gasoline with high sulphur levels affects tailpipe emissions and significantly contributes to atmospheric air pollution. This is due to the fact that sulphur in gasoline not only causes increased emissions of sulphur dioxide and sulphate particles from vehicles but also interferes with the performance of vehicle pollution control systems and results in higher emissions of other gaseous pollutants. The higher the sulphur level, the greater will be the increase in emissions of a number of other pollutants from vehicles.

Scientists and health experts have found evidence that emissions of pollutants from vehicles cause considerable harm to the health of Canadians and to the environment. The combustion of gasoline is in fact the largest national source of emissions of the combination of sulphur dioxide, sulphates, nitrogen oxides, volatile organic compounds and carbon monoxide. Thus, reduction in the level of sulphur in gasoline becomes one of the most important policy initiatives to improve health through the improvement of the environment.

Two other considerations reinforce the necessity and urgency of lowering the level of sulphur in gasoline. First, as emissions from vehicles are a function of vehicle technology and the properties of the fuels, a lower level of sulphur in gasoline will make the vehicle

[4] For example, the average level of sulphur in Ontario was significantly higher than the rest of the country.

pollution control systems function more efficiently. Although vehicle manufacturers made considerable progress in 1980s and 1990s to increase the efficiency of the combustion process and improve the emission control systems, sulphur levels in gasoline were not regulated. Hence, the benefits of the automobile emission control technologies could not be fully achieved without the reduction of the sulphur content of the fuel. Without the use of low sulphur fuels the catalytic converters installed in the vehicles would in some cases not work properly causing the vehicles to continue to emit high levels of pollutants.

Second, the absence of regulations to mandate low sulphur gasoline will hinder the future development of new high efficient engine technologies, if such technologies are sensitive to the sulphur content of the fuel. This has important implications for Canada's objective to control its greenhouse gas emissions in the future.

If no specific actions were taken by governments and the petroleum industry to limit the sulphur content of gasoline, the problem of atmospheric pollution would get worse over time and the health of Canadians and the environment would be further jeopardized.

III. Setting Objectives

Because in the 1990s the total volume of the sulphur emissions from gasoline had increased dramatically in some regions of Canada, and because significant health and environmental impacts were created as a result of the existing levels of sulphur in gasoline, the regulatory authorities were required to determine whether government interventions were needed and, if needed, to what extent it should intervene.

The general view is that the level of sulphur in gasoline should be set so that the costs associated with compliance with the regulation are less than the associated health and environmental benefits. Presumably, there is a trade-off between the magnitude of net economic benefits and the compliance costs of the regulations. Eventually the incremental economic costs will increase at a faster rate than the economic benefits;

hence the incremental net economic benefits will become negative. Cost-benefit analysis is the tool recommended by the Canadian Regulatory Guide to assess the benefits and costs of such regulations to determine their appropriate stringency.

As of 1997, the Canadian gasoline had an average sulphur content of 360 ppm. The levels of sulphur differed by region. Sulphur in gasoline, for example, was around 530 ppm in Ontario while in other regions, the sulphur levels ranged from 260 to 290 ppm. The objective was to constrain the national sulphur level in gasoline so that from January 1, 2001 it would never be higher than the national average in 1997. This implied that the Canadian average of 360 ppm should be maintained in the interim from 1997 to 2000. This would likely require certain refineries to adjust their operations in order to not exceed this 1997 level.

IV. Developing Alternative Scenarios

Once the broad objectives of lowering the sulphur in gasoline were set, alternative command and control scenarios could be formulated in terms of the sulphur concentration. Their incremental benefits and costs could be compared with the “without regulation” or base case scenario. Each of the alternative scenarios should be considered as one of the “with regulation” scenarios.

The alternative scenarios and the base case are developed on the basis of the sulphur reductions in gasoline that would come into effect on January 1, 2001. This is an ex ante evaluation, using data collected and projections made before the regulation was implemented. The baseline scenario is important to be clearly defined, so that the impact of alternative scenarios can be properly understood.

Base Case

In this case, the analysis of the situation was undertaken in 1997 and 1998, but no major regulatory reforms were made to the sulphur content in gasoline before the end of 2000.

The base case assumes that the gasoline produced at each refinery in the future would have the same sulphur content as in 1997. If significant changes to refinery operations are expected, the level of sulphur in gasoline is expected to be at its new level for each refinery by the end of 2000. Thus, the assessments of individual refineries are made in order to determine the cost implications for the case. The information provided by refiners indicates that the average level of sulphur in Canadian gasoline is expected to be 410 ppm in 2000. As a result, changes in some refineries are expected to be required in order to meet the anticipated sulphur level of 410 ppm by the end of 2000. Therefore, the base case is established with the level of sulphur maintained at 410 ppm over the study period from 2001 to 2020.

Alternative scenarios

Six alternative scenarios are developed for consideration. They represent a scale of increasingly restrictive sulphur-in-gasoline regulations. All scenarios are required to have a maximum annual average level of sulphur in the gasoline from each refinery. The same can be expected for independent suppliers of gasoline. All gasoline produced or imported is subject to a rule that specifies a never-to-be-exceeded level of sulphur. The scenarios specified below are designed so that the regulation would become effective January 1, 2001.

Scenario 1: 360 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 360 ppm and the level of sulphur to never exceed 420 ppm.

Scenario 2: 250 ppm Sulphur in Gasoline

This sets the maximum annual average level of sulphur in gasoline for each refinery to be at 250 ppm and the level of sulphur to never exceed 300 ppm.

Scenario 3: 200 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 200 ppm and the level of sulphur to never exceed 250 ppm.

Scenario 4: 150 ppm Sulphur in Gasoline

Scenario 4 sets the maximum annual average level of sulphur in gasoline for each refinery to be at 150 ppm and the level of sulphur to never exceed 200 ppm.

Scenario 5: 100 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 100 ppm and the level of sulphur to never exceed 150 ppm.

Scenario 6: 30 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 30 ppm and the level of sulphur is never to exceed 80 ppm.

V. Assessing Benefits and Costs of Alternative Options

In order to measure the incremental benefits and cost of alternative options vs. the baseline scenario, one can either estimate both the gross annual benefits and cost of alternative options and the baseline scenario or simply estimate the incremental annual benefits and costs of alternative options in excess of the baseline scenario. In this case study, we adopt the second approach.

5.1 Measurement of Costs

The costs are the outlays made to purchase the resources used to implement the regulatory option. They include two types of costs: the compliance costs incurred by suppliers of fuels and the administrative costs incurred by government.

5.1.1 Compliance Costs by the Private Sector

There are 17 refineries that produce fuels in Canada.[5] Because the circumstances of each refinery are different, the changes required to meet the specification of each scenario will be different. Each refinery will employ a number of different strategies to reduce sulphur in gasoline both in the base case and in the six alternative scenarios. Each refinery has different sulphur reduction break points, depending upon their crude slate, their present gasoline sulphur level, and the flexibility of the existing refinery. They include reallocation of heavy fluid catalytic cracker (FCC) gasoline to mid distillates, heavy FCC gasoline end point reduction, FCC unit catalyst change, FCC gasoline desulphurization, extractive Merox of light gasoline, FCC gasoline recycle to the FCC unit for recracking and FCC unit feed desulphurization.[6] The total capital investment for each of the six scenarios for the nation as a whole is assumed to be incurred in 2000. In addition, annual operating costs are also incurred, beginning in 2001. All costs expressed below are estimated in 1995 prices.

As was mentioned earlier, the alternative scenarios were based on sulphur reductions in gasoline that become effective on January 1, 2001. The volume of gasoline produced for each of the scenarios is 36 billion litres per year.

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[5] Of the 17 refineries, 15 participated and provided cost estimates to the Cost and Competitiveness Assessment Panel Study Group. Costs of the two non-participating refiners are estimated by the study group.

[6] A technical discussion regarding FCC gasoline sulphur reduction alternatives can be found in the Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *The Costs of Reducing Sulphur in Canadian Gasoline and Diesel*, (March 1997).

Estimates of the capital and operating costs for the base case and alternative scenarios are based on the assumptions that (a) the annual demand growth rate for gasoline is 0.7 percent, and (b) the year for producing the reformulated fuels is year 2000. With this assumption, the capital costs reflect changes in facilities required by refineries to meet the regulation set by each scenario.[7] They are described below.

Scenario 1: 360 ppm Sulphur in Gasoline

This scenario requires the maximum annual average level of sulphur in gasoline for each refinery to be not more than 360 ppm and the level of sulphur at any time during the year should never exceed 420 ppm. Of the 17 existing Canadian refineries, 8 will require capital investment to achieve the 360 ppm level for gasoline. Most refineries would choose to desulphurize the heavy FCC gasoline. However, some have diverted the heavy gasoline to the mid distillate light cycle oil desulphurization unit. The product is refractionated and returned to the gasoline pool. Some refineries will be able to achieve the 360 ppm sulphur level by varying the crude sourness, employing a selective FCC unit catalyst which reduces the FCC gasoline sulphur level or diverting some heavy FCC gasoline to mid distillates. A small amount of methyl tertiary butyl ether (MTBE) is generally imported to offset the octane loss.

Under this scenario, there will be no capital investment required in the Western Region. As a result, to achieve this level of sulphur in gasoline a total capital investment of $177 million is required nationally, of which 54 percent will be incurred in the Ontario region. The annual operating costs are estimated at about $24 million per year for the study period.

[7] For the base case, it would require $209 million for gasoline, expressed in 1995 prices. Of the $209 million, the percentages spent in the Atlantic and Quebec region will be 37.8%, 22.5% in Ontario, and 39.7% in Prairies and British Columbia.

Scenario 2: 250 ppm Sulphur in Gasoline

Scenario 2 requires the maximum annual average level of sulphur in gasoline for each refinery to not exceed 250 ppm with the level of sulphur never exceeding 300 ppm at any point during the year. Like Scenario 1, most refineries would choose to desulphurize the heavy FCC gasoline. Other refineries would divert the heavy FCC gasoline to the mid distillate desulphurization unit. This product is either left in the mid distillate pool or returned to the gasoline pool, depending upon the best method of balancing the gasoline volumetric needs. Other investments would include investments for amine regeneration and sulphur plant capacity. A small amount of MTBE is imported to offset the octane loss.

The incremental capital and annual operating costs for this scenario are estimated at $360 million and $61 million per year, respectively.

Scenario 3: 200 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 200 ppm and the level of sulphur at any point must never exceed 250 ppm. Of the 17 existing refineries, 12 will be affected. Like the first two scenarios, most refineries would choose to desulphurize the heavy FCC gasoline while other refineries would divert the heavy cat naphtha to the light cycle oil hydrodesulphurizer. Other capital expenditures include investments for amine regeneration and sulphur plant capacity. A small amount of MTBE is imported to offset the octane loss.

The total capital expenditures that would be needed by the 12 refineries to reach this standard are estimated at $585 million. The annual operating costs would be increased approximately $63 million per year over the 20-year impact period.

Scenario 4: 150 ppm Sulphur in Gasoline

Scenario 4 sets the maximum annual average level of sulphur in gasoline for each refinery to be at 150 ppm and at no point should the level of sulphur exceed 200 ppm. This scenario will affect 14 refineries. Like the previous scenarios, the heavy FCC gasoline cut is desulphurized in a new technology desulphurization unit while the light FCC gasoline cut is partially desulphurized depending on the sourness of the total FCC gasoline stream. Again, a small amount of MTBE is imported to offset the octane loss.

The total capital expenditures for this scenario expressed in 1995 prices are estimated to be about $697 million. Starting in 2001, the annual operating costs are estimated at $89 million per year.

Scenario 5: 100 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 100 ppm and at no point should the level of sulphur exceed 150 ppm. In this scenario, refineries are generally faced with desulphurizing the full range of the FCC gasoline stream. In addition, several refineries will produce an intermediate FCC gasoline cut to offset the octane loss, effectively achieving total desulphurization of this particular stream. Some reformer debottlenecking is identified in this scenario to offset the octane loss. Other investments include additional hydrogen, sulphur and amine plant capacity.

The total capital investments for this scenario are estimated at $893 million. They are spread across the country with 31.6% in the Atlantic Provinces and Quebec, 43.9% in Ontario, and 24.5% in the Prairie Provinces and British Columbia. The operating costs are estimated at $117 million per year.

Scenario 6: 30 ppm Sulphur in Gasoline

This scenario sets the maximum annual average level of sulphur in gasoline for each refinery to be at 30 ppm and the level of sulphur during the year should never exceed 80 ppm. This scenario will impact 16 refineries since few refineries have specified FCC unit feed hydrodesulphurizers. FCC feed hydrotreating is a significant capital investment, reflecting the cost of a high pressure complex process. However, the refinery's ability to process lower quality crude oils is also significantly increased, which has been taken into account in the scenario in which refineries choose the FCC unit hydrotreating.

Other refineries will choose to desulphurize all the FCC gasoline by either a full range FCC gasoline desulphurizer or selective light and heavy FCC gasoline desulphurizers. Other investments include the desulphurizing of straight run naphthas, or any sulphur bearing naphthas not already treated. Also included are the investment outlays made by some refineries for hydrogen, amine regeneration and sulphur plant capacity.

The total capital expenditures for this scenario are estimated at $1,788 million. They are about double these expenditures required by Scenario 5. These investments are spread over the country with 29.8% occurring in the Atlantic Provinces and Quebec, 36.3% in Ontario, and 33.9% in the Prairie Provinces and British Columbia. The annual operation costs will be increased by about $119 million.

The estimated total incremental capital and annual operating costs are summarized in Table 1.

Table 1
Total Investment and Annual Operating Costs by Scenario and by Region
(millions of dollars in 1995 prices)

Scenario	Costs	Atlantic and Quebec	Ontario	Prairies and British Columbia	Canada
Base Case	Investment Cost	79.0	47.0	83.0	209.0
	Annual Operating Cost	28.5	34.2	11.1	74.0
Alternative Options					
Scenario 1: 360 ppm	Investment Cost	81.0	96.0	0	177.0
	Annual Operating Cost	16.6	7.0	0.3	23.9
Scenario 2: 250 ppm	Investment Cost	144.0	196.0	20.0	360.0
	Annual Operating Cost	28.5	16.0	16.5	61.0
Scenario 3: 200 ppm	Investment l Cost	226.0	213.0	146.0	585.0
	Annual Operating Cost	31.7	24.0	7.7	63.4
Scenario 4: 150 ppm	Investment Cost	243.0	266.0	188.0	697.0
	Annual Operating Cost	38.4	35.1	15.0	88.5
Scenario 5: 100 ppm	Investment Cost	282.0	392.0	219.0	893.0
	Annual Operating Cost	45.3	48.9	22.8	117.0
Scenario 6: 30 ppm	Investment Cost	532.0	650.0	606.0	1,788.0
	Annual Operating Cost	49.7	47.5	21.9	119.1

Sources: Kilborn, Inc.,*The Costs of Reducing Sulphur in Canadian Gasoline and Diesel*, Phase III, (March 1997); and Government of Canada, *Final Report of the Government Working Group on Sulphur in Gasoline and Diesel Fuel – Setting a Level for Sulphur in Gasoline and Diesel*, (July 14, 1998), Table 2.3

5.1.2 Administrative Costs by Governments

In order to enforce the regulations, governments are expected to incur some additional costs. It would require one full-time employee and $30,000 in annual operating and overhead costs. The total incremental costs of enforcing the regulation are estimated at approximately $59,000 in 2000 prices per year in the first three years.[8] Costs are expected to decrease in subsequent years once industry establishes new systems and procedures. For the purpose of this analysis, annual administrative costs of $60,000 are assumed. These additional costs should be counted as part of the economic cost for each of the alternative scenarios.

5.2 Measurement of Benefits

Evaluating the impacts of reducing the sulphur level in gasoline on human health and the environment is the most difficult and challenging task. It involves two main issues. First, what types of emissions would be generated from vehicles as a consequence of the

[8] Canada Gazette Part I, *Sulphur in Gasoline Regulations*, (October 31, 1998).

sulphur concentration in gasoline, and what are the impacts of those emissions on ambient concentrations? Second, what is the ambient concentrations impact on the health of Canadians and their environment, and what are the values of those effects?[9]

The basic methodology used is the damage function approach that provides the scientific assessment of the impacts of varying levels of sulphur in gasoline on ambient air pollution concentrations, which, in turn, affect the environment and human health. For each of the alternative scenarios, the measurement of the benefits is done in four stages:

- the change in vehicle emissions caused by changes in the level of sulphur in gasoline;
- the change in ambient air quality affected by changes in emitted pollutants by vehicles;
- the impact on environment and human health by changes in ambient air quality; and
- the assessment of the impact on environment and health in monetary value.

5.2.1 Reductions in Sulphate Concentrations

The first step of the impact analysis of reducing the level of sulphur in gasoline on human health and the environment is to assess the improvements expected in air concentrations of specific substances. The ambient air model estimates the changes in emitted particles and gases such as sulphates, fine particles ($PM_{2.5}$), sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and ground level ozone, resulting from reduction of specific level of sulphur. Since they are influenced by the existing sulphate level and the air quality of the region, the vehicle density, and other geographical factors, the focus of the analysis will be on seven cities across the country. The cities are Vancouver, Edmonton, Winnipeg, Toronto, Montreal,

[9] Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997).

Saint John, and Halifax.[10] The information is collected in 1995 with the population and sulphate levels as shown in Table 2 and then updated and projected up to the end of year 2000, the beginning of the impact analysis period. The results are then extrapolated to the nation as a whole.

Table 2
Population and Sulphate Levels for Seven Cities in 1995

Cities	Total population	Sulphate (µm/m^3)
Halifax	330,845	4.1
St. John	124,981	3.2
Montreal	3,189,824	4.2
Toronto	4,004,463	4.4
Winnipeg	616,790	1.8
Edmonton	876,290	1.6
Vancouver	1,542,745	2.1

Sources: Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), p. 3-4.

According to health experts, many potential human health illnesses may be associated with air pollution, and not all potential impacts can be quantified. The most appropriate way to address atmospheric changes is to select a pollutant for which significant change can be projected and for which a sufficient health impact database also exists. The health experts conclude that the dominant gaseous pollutant is sulphur dioxide and the dominant particulate matter component is sulphate. The sulphate aerosol is emitted directly from catalyst-equipped vehicles and is also formed in the atmosphere by the oxidation of SO_2. Lowering the level of sulphur in gasoline will reduce emissions of CO, NO_x and VOCs. It is difficult to identify suitable damage functions for each of these pollutants independently; hence sulphate is selected as the best index of the mixture. Equally important for this case study is the availability of health and environmental literature which relate sulphate with various health outcomes.

[10] Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Atmospheric Science Expert Panel Report*, (August 14, 1997).

Using the atmospheric model, one can estimate the central value of sulphate concentration reductions in the seven cities for all six alternative scenarios. The estimates are also made for 2020, the last year of the impact period. Due to the uncertainty associated with the response function, the low and high values of sulphate concentration reductions are also estimated for the two scenarios presented in Table 3.

Table 3
Sulphate Concentration Reductions for Alternative Scenarios in Year 2001 and 2020
($\mu g/m^3$)

Cities	Year	Scenario									
		1	2	3	4			5	6		
		C	C	C	L	C	H	C	L	C	H
Halifax	2001	0.04	0.04	0.07	0.06	0.08	0.10	0.09	0.08	0.11	0.15
	2020	0.04	0.05	0.08	0.06	0.09	0.12	0.10	0.09	0.13	0.17
St. John	2001	0.02	0.02	0.03	0.02	0.03	0.04	0.04	0.04	0.05	0.06
	2020	0.02	0.02	0.04	0.03	0.04	0.06	0.05	0.04	0.06	0.08
Montreal	2001	0.04	0.05	0.06	0.05	0.07	0.09	0.08	0.07	0.09	0.13
	2020	0.04	0.06	0.07	0.06	0.08	0.11	0.09	0.08	0.11	0.14
Toronto	2001	0.14	0.19	0.22	0.18	0.25	0.33	0.28	0.23	0.31	0.42
	2020	0.16	0.23	0.27	0.21	0.30	0.39	0.33	0.27	0.38	0.49
Winnipeg	2001	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.03
	2020	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.03
Edmonton	2001	0.00	0.00	0.01	0.01	0.02	0.03	0.02	0.03	0.03	0.05
	2020	0.00	0.00	0.01	0.02	0.02	0.03	0.03	0.03	0.05	0.07
Vancouver	2001	0.01	0.02	0.03	0.03	0.04	0.06	0.06	0.06	0.08	0.12
	2020	0.02	0.02	0.04	0.04	0.05	0.07	0.08	0.08	0.11	0.15

Notes: L, C, and H refer to the low, central, and high value, respectively.

Sources: Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Atmospheric Science Expert Panel Report*, (August 14, 1997), pp. 117, 194; Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), p.3-3.

5.2.2 Impact on Health and Environment

The reductions in ambient air pollution concentrations will have an impact on the environment and on human health. The functional relationship between ambient air pollution concentration and a number of human health responses has to be established from the epidemiologic research and quantified. They are available from literature in which sulphate is employed as the sole index of all air pollutants to be reduced by alternative scenarios under consideration. For each health outcome, a reduction in ambient sulphate concentration is found to result in proportional reductions in the number of adverse health events in the population.

That being said, there still has been a considerable uncertainty regarding health effects associated with air pollutants. Therefore, for each concentration response relationship, the low, central, and high values are estimated. The central estimate is generally selected from the middle of the range reported in various studies and is considered as the most likely results of that health effect. The selected range of low and high estimates is based on the variation in results across the studies and the judgment made by the experts in the field.

Each of the low, central, and high estimates is assigned a probability weight. These probability weights are combined with the low, central, and high estimates to create a probability distribution of expected total health benefits. Table 4 presents the selected concentration-response estimates used in this study for each of the health effects. These response estimates are measured for a microgram per cubic meter ($\mu g/m^3$) change in the annual average sulphate concentration.

The major health effects can be classified according to their impact on mortality and morbidity. The effects of different levels of ambient air quality on mortality and morbidity are estimated here using the benefit transfer approach, which relies on information obtained from existing scientific studies. The estimates from related scientific research done elsewhere are adjusted to reflect the circumstances of the situation in Canada. They are discussed and estimated in the following section.

Table 4
Estimated Health Responses for a 1 μg/m^3 Change in Annual Sulphate Concentration

Health Effect Category	Concentration-Response Parameters: Values of Range	Weights	Sources
Premature Mortality Risk	L: 1.14×10^{-5} C: 2.54×10^{-5} H: 5.70×10^{-5}	22% 67% 11%	Pope et al. (1995); Schwartz et al. (1996)
Chronic Respiratory Disease	For population 25 years and over: L: 7.06×10^{-5} C: 1.35×10^{-4} H: 2.00×10^{-4}	25% 50% 25%	Abbey et al. (1995)
Respiratory Hospital Admissions (RHAs)	L: 1.30×10^{-5} C: 1.60×10^{-5} H: 1.80×10^{-5}	25% 50% 25%	Burnett et al. (1995)
Cardiac Hospital Admissions (CHAs)	L: 1.00×10^{-5} C: 1.30×10^{-5} H: 1.70×10^{-5}	25% 50% 25%	Burnett et al. (1995)
Emergency Room Visits (ERVs)	L: 8.40×10^{-5} C: 1.10×10^{-4} H: 1.20×10^{-4}	25% 50% 25%	Stieb et al. (1995)
Asthma Symptom Days (ASDs)	For population with asthma (6%): L: 3.30×10^{-1} C: 6.60×10^{-1} H: 9.90×10^{-1}	25% 50% 25%	Ostro et al. (1991)
Restricted Activity Days (RADs)	For non-asthmatic population (94%) aged 18 years and over: L: 1.55×10^{-2} C: 2.68×10^{-2} H: 3.81×10^{-2}	25% 50% 25%	Ostro (1990)
Days with Acute Respiratory Symptoms (ARSs)	For non-asthmatic population (94%): L: 0.46×10^{-1} C: 1.41×10^{-1} H: 2.32×10^{-1}	25% 50% 25%	Ostro et al. (1993)
Lower Respiratory Illness	For population under age 18: L: 2.70×10^{-3} C: 4.40×10^{-3} H: 6.20×10^{-3}	25% 50% 25%	Dockery et al. (1996)

Sources: Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), p. 4-5.

5.2.2.1 Premature Mortality Risk

The epidemiologic studies have consistently found a significant relationship between air pollution and mortality over a wide range of particulate matter concentrations. Many cross-section and time-series studies were conducted in the U.S. to confirm that there is a statistically significant relationship between mortality rates and particulate matter levels in the air. For example, Pope et al. (1995) found a mortality-ratio of 1.15 and 1.17 for sulphates and fine particles, respectively, based on samples of individuals in 151 cities ranging from the most polluted to least polluted city over the 7-year study period. Other studies also found long-term exposure to high average particulate matter concentrations are associated with higher risks of premature mortality. Some time-series studies also found statistically significant associations in a wide range of cities between daily mortality and daily fluctuations in particulate matter concentrations. Such studies considered only short-term effects and do not reflect the potential adverse consequences of chronic exposures to air pollution.

As was previously mentioned, sulphates are used as the air pollution index for this study since they represent the majority of the particulate mass to be reduced by removing sulphur from fuels. The results from time-series studies are used to develop the low estimate of the premature mortality change associated with a reduction in air pollution while those from cross-sectional studies are employed to derive the high estimate. The central estimate is based on a weighted average of the effect estimates from the time-series and cross-sectional studies.

We use the low estimate of the sulphate concentration/premature mortality coefficient derived from Schwartz et al. study (1996). This estimate is found by dividing the mean mortality effect size (for a 5^{th} to 95^{th} percentile increase in sulphate) minus one standard deviation by the mean 5^{th} to 95^{th} percentile change in sulphate concentration. It is equal to 0.17% [= (3.8 – 0.8)% / (17.0 $\mu g/m^3$ SO_4)] change in mortality per $\mu g/m^3$ SO_4.

The high estimate of the sulphate concentration/premature mortality coefficient is based on the Pope et al. study (1995). That is calculated as the ratio of the mean mortality effect (for the most polluted vs. the least polluted) plus one standard deviation to the mean sulphate concentration difference between the most polluted and the least polluted areas. This is equal to 0.85% [= ln (1.15 + 0.035)/19.9] change in total mortality per $\mu g/m^3$ SO_4.

The central estimate of the premature mortality effect coefficient is a weighted average of the low and the high estimates where the weights are two-thirds assigned for the low estimate and one-third for the high estimate, based on suggestion made by health experts. It is estimated at 0.38% change in total mortality per $\mu g/m^3$ SO_4.

Multiplying the above percentages by the prevailing baseline Canadian nonaccidental yearly death rate of 6,700 persons per million would yield the health effect response -- concentration-response -- to per $\mu g/m^3$ change in annual sulphur concentration for Canada. The results are 1.14×10^{-5} for low estimate, 2.54×10^{-5} for central estimate, and 5.70×10^{-5} for high estimate and their corresponding probabilities of occurring are 22%, 67% and 11%. One can then estimate the number of mortality each year in a specific city by applying these concentration-response coefficients to the size of the population living in the city.

5.2.2.2 Acute and Chronic Morbidity

In addition to premature mortality risk, it is important to identify the main morbidity effects associated with air pollution. This includes effects ranging from chronic respiratory disease to some respiratory symptoms as a consequence of reducing sulphur in gasoline.

(a) Chronic Respiratory Disease

Higher ambient particulate matter exposures have recently been found by health experts to be associated with higher rates of chronic respiratory disease, although quantifying specific concentration-response is more difficult. Using a large sample of nonsmoking adults in California, Abbey et al. (1995) examined changes in chronic respiratory disease incidence to exposure over a 10-year period and confirmed chronic respiratory disease outcomes from both fine particles and sulphates. Sulphur was found to be associated with changes in the severity of airway obstructive disease (AOD) and chronic bronchitis over the study period. The partial effect of sulphates can then be calculated as follows:

$$\Delta AOD = b \cdot p \cdot (1-p) \cdot \Delta SO_4$$

where b stands for estimated regression coefficient and p for the baseline prevalence of AOD.

The logistic regression coefficient was estimated by Abbey et al. at 0.0174 with a standard error of 0.0083. The baseline prevalence is 8.5%. The increase in AOD over a ten-year period per unit sulphate is estimated at 0.00135, and the effect per year per one $\mu g/m^3$ change in sulphate would be 1.35×10^{-4}. The lower and upper estimates, based on $\pm$ one standard error would be 7.06×10^{-5} and 2.00×10^{-4}, respectively. The probability weight selected for the central estimate is 50%, with 25% assigned for the low and high estimates.

(b) Hospital Admissions

Studies by Burnett et al. (1995, 1997), Thurston et al. (1997), and others have indicated an association of ambient air pollution (including sulphates) with both respiratory hospital admissions (RHAs) and cardiac hospital admissions (CHAs) for Ontario. Based on the results of Burnett et al., it was estimated that there is a 3.5% increase in RHAs for a 13 $\mu g/m^3$ increase in sulphate. The average daily RHA for the study period was 16 per million persons. Thus, the daily RHA per $\mu g/m^3$ sulphate is 4.31×10^{-8} [$= 0.035 \times (16.0 \times 10^{-6}) / 13$]. Multiplying this figure by 365 yields the central estimate of annual number of RHAs for a change in annual sulphate concentration. That is 1.57×10^{-5}. The low and high estimates selected as the central value ± one standard error, are 1.3×10^{-5} and 1.8×10^{-5}, respectively.

Burnett et al. also reported a 3.3% increase in CHAs for a 13 μg/m³ increase in sulphate. The average daily CHAs were 14.4 per million population. Thus, the daily CHAs per μg/m³ sulphate would be 3.66×10^{-8} [= 0.033 x (14.4 x 10^{-6}) / 13]. Multiplying this figure by 365 yields the estimated annual number of RHAs for a change in annual average sulphate concentration; that is 1.34×10^{-5}. The low and high estimates selected as ± one standard error of the central estimate, are 1.0×10^{-5} and 1.7×10^{-5}, respectively.

(c) Emergency Room Visits

Based on the Saint John Particle Health Effects Study, Stieb et al. (1996) found that, for each respiratory disease hospital admissions in St. John, New Brunswick, there are 5.3 visits for respiratory diseases and 1.4 visits per admission for cardiac diseases. Using these ratios and the risk coefficients derived for hospital admissions in the previous section, we can estimate the response coefficients in terms of expected annual change in emergency room visits per annual average μg/m³ as follows:

Low: $[5.3 \times (1.3 \times 10^{-5})] + [1.4 \times (1.0 \times 10^{-5})] = 8.3 \times 10^{-5}$;
Central: $[5.3 \times (1.6 \times 10^{-5})] + [1.4 \times (1.3 \times 10^{-5})] = 1.1 \times 10^{-4}$;
High: $[5.3 \times (1.8 \times 10^{-5})] + [1.4 \times (1.7 \times 10^{-5})] = 1.2 \times 10^{-4}$.

(d) Asthma Symptoms

Several epidemiologic studies have shown the frequency of increasing asthma symptoms (such as shortness of breath or wheezing, and/or in use of medication relative to what was "normal" for that individual) as a function of ambient particulate matter concentrations. These studies first diagnosed each individual's asthmatics record daily asthma symptoms and then examined their relationship with daily particulate matter and ozone levels. Ostro et al. (1991) examined the association between air pollutants such as sulphates, $PM_{2.5}$, and acidic aerosols and changes in asthma symptoms days among adults during winter months in Denver. They found an increase of one log unit of sulphate was associated with a 0.0077 increase in the symptoms. The prevalence of daily shortness of breath during the study period was 18% and the average level of sulphate was 2.11 $\mu g/m^3$. This implies that an increase in sulphate of per $\mu g/m^3$ would result in an increase in 0.0036 [= 0.0077/2.11] probability of symptoms. Since this figure is only applied in winter months, the central estimate of the response coefficient per year would be 6.6×10^{-1}. The low and high estimates based on one standard error are estimated at 3.3×10^{-1} and 9.9×10^{-1}, respectively.

It should be noted that the above estimates are based on the assumption that 6 percent of the population has asthma.

(e) Restricted Activity Days

There are studies that support a strong relationship between restricted activity days (RAD) and fine particles such as sulphates. For example, base on the U.S. EPA's Inhalable Particle Monitoring Network over three year period, Ostro (1990) estimated that a one $\mu g/m^3$ change in sulphate would increase RAD by 0.83% with a standard error of 0.35%. This was obtained from the study sample experiencing 3.23 RADs for respiratory conditions per year per individual. This implies that the central estimate for RADs is equal to 0.0268 (= 0.0083 x 3.23). The low and high estimates based on one standard error from the central value would be 0.0155 and 0.0381, respectively.

Since about 6% of the general public has diagnosed asthma and should be excluded from the RAD studies, the RAD concentration-response function is only applied to the non-asthmatic portion (94%) of the population.

(f) Acute Respiratory Symptoms

Using a logistic regression model and controlling for weather, gas stove use, time, gender and the existence of chronic disease, Ostro et al. (1993) have found a statistically significant association between sulphate and lower respiratory symptoms (defined as dry cough, cough with phlegm, shortness of breath, chest cold, croup, asthma, bronchitis, flu or pneumonia). The prevalence of lower respiratory symptoms was 1.5%. The results indicated that a 10 $\mu g/m^3$ change in sulphate was associated with an odds ratio of 1.30 (95% CI = 1.09 – 1.54). The associated regression coefficient is estimated at 0.0262 (= ln 1.3) per $\mu g/m^3$ with a standard error of 0.009. The annual effect of sulphates can be calculated as follows:

$$b \cdot p \cdot (1 - p) \cdot 365 = (0.0262)(0.015)(0.985)(365) = 0.141$$

where b is the estimated response coefficient and p is the baseline prevalence of lower respiratory symptoms. The low and high estimates measured in terms of expected annual increase in lower respiratory symptoms are 0.046 and 0.232. Again, the acute respiratory symptoms concentration-response function is only applied to the non-asthmatic portion (94%) of the population.

(g) Lower Respiratory Illness in Children

Dockery et al. (1996) found the strong relationship between lower respiratory illness in children and particulate matter concentrations in 24 cities in the U.S. and Canada. Among the cities, the prevalence rates for bronchitis ranged from 3 to 10%. The results indicated a statistically significant association between sulphate and acute bronchitis in which a 6.8 $\mu g/m^3$ increase in annual sulphate was associated with an odds ratio of 1.65. The associated regression coefficient would be 0.0736 [= (ln 1.65)/6.8] with a standard error of 0.029. This implies that with a 6.5% baseline prevalence of lower respiratory illness, a one $\mu g/m^3$ change in sulphate would generate a central estimate of 0.0044 (= 0.073 x 0.065 x 0.935). Using the central estimate ± one standard error, the low and high estimates measured in terms of expected annual increase in children's lower respiratory illness would be 0.0027 and 0.0062.

5.2.2.3 Other Considerations

It should be noted that several of the broad categories for acute morbidity health effects may include other effects because of using the same Canadian hospital data. In such cases, the overlapping categories are removed in order to avoid double counting. For example, all days in the hospital or emergency room visits (ERVs) are also restricted activity days (RADs). Thus, net ERVs are obtained by subtracting days for respiratory hospital admission (RHAs) and cardiac hospital admission (CHAs) from the total ERVs. In addition, all RADS are also acute respiratory symptom days (ARSs) and thus a fraction of RADs is subtracted from ARSs to obtain net ARSs. In their study, Ostro et al. (1993) indicated that 28% of the ARSs include a lower respiratory symptom. Hence, in this study RADs are split between upper and lower respiratory symptoms in the same proportions and the lower respiratory RADs are subtracted from ARSs because the latter only include days with lower respiratory symptoms.

Furthermore, lowering sulphur in gasoline will also reduce sulphur dioxide, sulphate, and carbon dioxide in the environment that may independently reduce harm to human health as well as result in other benefits in the areas of agriculture, forestry and aquatic organisms.[11] Insufficient information has been found to date to quantify these effects. Sulphur is a required nutrient for plant growth and the deposition of sulphate to agricultural soils may be helpful. Nevertheless, the reduction of sulphate deposition to agricultural soils has not been found to result in any negative impact on crop productivity. Again, no empirical evidence has been found for this relationship. Finally, some people claim that certain assets such as recreation areas, visibility, wildlife and wetland would be improved as a result of lowering particulate matters. It may be true but it is hard to be quantified.

[11] Sulphur dioxide and sulphate/acidity may be toxic to roots and disrupt processes related to reproduction or regeneration of plants.

5.2.2.4 Total Avoided Health Effects for Canada

With the sulphur concentration reductions for each of the alternative scenarios (Table 3), the health concentration-response (Table 4) and characteristics of seven selected cities, one can estimate each of the health outcomes of all seven cities for each of the nine scenarios in 2001 and 2020. Table 5 presents the central estimates of the annual number of adverse health effects to be avoided for the first year 2001 and for the last year 2020 of the study period. Using the geometric extrapolation, one can calculate each of the health effects for every year during the 20-year study period.

The seven cities considered so far account for 39 percent of Canada's population. To measure the national impact of changes in sulphur levels in fuels on human health, the above effects (Table 5) have to be adjusted upward. The increases in percentage are based on the results of each specific health effect projected by the Government Working Group for total Canadian population.[12] These percentages are 56% for acute respiratory symptom; 58% for premature mortality, respiratory hospital admissions, and cardiac hospital admissions; 60% for asthma symptom days and child lower respiratory illness; 61% for emergency room visits; 62% for chronic respiratory disease; and 63% for restricted activity days. As a result, the total numbers of health effects for Canada as a whole are first projected for the first and the last year of the impact period for each alternative scenario as shown in Table 6 and then extrapolated for each year between the first and the last year.

[12] Government of Canada, *Final Report of the Government Working Group on Sulphur in Gasoline and Diesel Fuel – Setting a Level for Sulphur in Gasoline and Diesel*, (July 14, 1998), p. vi.

Table 5
Reductions of Health Effects for Seven Cities in Year 2001 and 2020

Health Effects		Alternative Scenarios					
		Scenario 1: 360ppm	Scenario 2: 250ppm	Scenario 3: 200ppm	Scenario 4: 150ppm	Scenario 5: 100ppm	Scenario 6: 30ppm
Premature Mortality	2001	22	30	35	41	47	53
	2020	31	45	54	61	69	82
Chronic Respiratory Disease	2001	78	105	125	145	166	187
	2020	110	157	191	215	244	290
Respiratory Hospital Admissions	2001	14	19	22	26	29	33
	2020	20	28	34	38	43	52
Cardiac Hospital Admissions	2001	11	15	18	21	24	27
	2020	16	23	28	31	35	42
Emergency Room Visits	2001	70	94	113	131	149	168
	2020	99	141	172	193	219	261
Asthma Symptom Days	2001	34,200	46,100	55,000	64,000	72,800	82,300
	2020	48,500	69,000	83,800	94,500	107,200	127,500
Restricted Activity Days	2001	16,200	21,900	26,000	30,300	34,500	39,000
	2020	23,000	32,800	40,000	44,800	50,800	60,400
Acute Respiratory Symptoms	2001	117,000	157,500	188,000	218,000	249,000	281,400
	2020	166,000	236,000	287,000	323,000	366,300	435,600
Child Lower Respiratory Illness	2001	1,000	1,300	1,600	1,800	2,100	2,300
	2020	1,380	2,000	2,400	2,700	3,100	3,600

Sources: Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), Tables 6-1 and 6-3.

Table 6
Total Reductions of Health Effects for Canada over the 20-Year Period
(number of cases)

Health Effects	Alternative Scenarios					
	Scenario 1: 360ppm	Scenario 2: 250ppm	Scenario 3: 200ppm	Scenario 4: 150ppm	Scenario 5: 100ppm	Scenario 6: 30ppm
Premature Mortality	829	1,169	1,385	1,591	1,810	2,100
Chronic Respiratory Disease	3,013	4,184	5,040	5,752	6,555	7,600
Respiratory Hospital Admissions	533	735	874	1,002	1,126	1,324
Cardiac Hospital Admissions	423	593	717	814	924	1,076
Emergency Room Visits	2,694	3,733	4,524	5,153	5,854	6,800
Asthma Symptom Days	1,307,842	1,814,497	2,185,633	2,500,763	2,840,451	3,300,000
Restricted Activity Days	634,343	882,402	1,062,847	1,212,450	1,377,466	1,600,000
Acute Respiratory Symptoms	4,364,822	6,049,747	7,249,041	8,323,223	9,470,413	11,000,000
Child Lower Respiratory Illness	37,798	52,078	63,228	71,131	82,277	93,000

Note: The number of health effects is a simple summation of cases occurred over the 20-year period.

5.2.3 Valuation of Health Effects in Monetary Terms

This section measures each of the avoided health effects in monetary terms so that all the effects can be aggregated in monetary value. The approach is benefit transfer methods that relies on information available from existing studies in the U.S. and Canada. When the U.S. studies are used, the monetary values are converted from the U.S. currency to Canadian currency with the purchasing power parity index or the market exchange rate for the year in question.

5.2.3.1 Approach

The fundamental principle to measure various health effects is the willingness to pay (WTP) principle. The term refers to the maximum amount of money an individual would be willing to pay to improve human health, to avoid getting hurt or to obtain an environmental improvement. It generally asks people questions in surveys to elicit estimates of the willingness to pay for the improvement in certain health items.

As was classified in the previous section, the health effects resulting from lowering the sulphur content in gasoline and diesel fuels can be broadly divided into a reduction of risk of death and reductions in morbidity. The latter are further broken down into eight categories. There are items such as the value of human life that individuals cannot put a price. There are also items people are willing to pay more for than what is the amount they are being asked to pay. This may be due to the availability of public health services that are largely financed through the tax system. In this case, the cost-of-illness (including medical costs and lost income due to illness) can be substantially lower than WTP.

While WTP estimates are not available for health effects, cost-of-illness (COI) estimates are used and adjusted upward to reflect the economic or social benefits. The adjustment factor, WTP/COI ratio, is based on three studies (Rowe et al., 1984; Rowe and Chesrnut, 1986; Rowe and Neithercut, 1987). It ranges from 1.3 to 2.4. In other words, the estimate of the willingness to pay to avoid the morbidity costs ranges from 1.3 to 2.4 times the actual cost of illness outlays. For the purpose of this study, a WTP/COI ratio of 2.0 is used for estimating the WTP of morbidity effects.

5.2.3.2 Valuation of Mortality Risk

Lowering the level of sulphur in gasoline and diesel fuels will reduce the risk of premature death. The benefits of these risk reductions can be estimated in terms of the value of statistical lives (VSL). It is a measure derived from the aggregation of many small risks over an exposed population. For example, somebody would take a higher wage in exchange for a riskier job. In the case of environmental health risks, deaths occur from related illness rather than accidents, and tend to be associated more with the elderly people and those with already compromised health.

Many studies have been carried out to estimate the VSL using either the traditional approach or the life expectancy approach in Canada, the United States, the United Kingdom, and Australia in the past 15 years.[13] All the VSL estimates are based on samples of working-age adults. The values range from $1.0 million to $12.8 million in 1994 prices. For the purpose of this study, $3 million, $5 million, and $10 million are selected for the low, central, and high estimates, respectively.

There are studies that provide evidence regarding how the value of WTP for reducing risks may change with the age of the person. Based on the Jone-Lee et al. study (1985), a downward adjustment of 75% is appropriate to be applied to the estimated value for those aged 65 and over. The adjustment is also made to account for the fact that since the majority of changes in mortality resulting from changes in air pollution are experienced by individuals over the age of 65, we calculate a weighted average VSL based on the assumption that 85% of the mortality is experienced by people aged 65 and over. The results are presented in Table 7. Moreover, the probabilities associated with the low,

[13] Detailed discussions can be found in Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), Chapter 5. The traditional approach provides an annual estimate of excess deaths reduced while the life expectancy approach estimates the change in life expectancy implied by the change in sulphates, multiplying by the population in each cohort, as well as a WTP for the change in life expectancy for each age group.

central, and high estimates of the VSL are assumed to be 33%, 50%, and 17%, respectively.[14] The lower probability for the high estimate is due to fewer studies in literature that provide high estimates of VSL. Because of the high percentage of lower estimated value associated with premature mortality, this study will be conservative in quantifying the health benefits.

Table 7
Monetary Values for Mortality Effects
(millions in 1994 prices)

	Low Estimate	Central Estimate	High estimate
Individuals > 65 Years Old	$2.3	$3.8	$7.5
Individuals < 65 Years Old	$3.0	$5.0	$10.0
Age-Weighted Average	$2.4	$4.0	$7.9
Probability Associated with the Selected Estimates	33%	50%	17%

Sources: Joint Industry/Government Study Sulphur in Gasoline and Diesel Fuels, *Health and Environment Impact Assessment Panel Report*, (June 25, 1997), Table 5-7.

5.2.3.3 Valuation of Morbidity Effects

WTP is also the tool used to measure various morbidity effects. When WTP estimates are not available, the estimates are based on COI information and an adjustment factor is applied to reflect the socio-economic value to the individuals who will be affected positively by regulation. The COI includes medical costs incurred and the social opportunity cost of individual's time because of illness. The latter is measured by the average wage rate to reflect the loss of labor productivity in society. For simplicity, the average wage is also used to proxy the cost of time for individuals who are not working in the formal labor market. This may overstate the values for the elderly and homemakers. In 1994, the average daily wage rate for all workers in Canada was $113.

What follows is a brief explanation of how each of the morbidity effects is estimated.

[14] With these weights, the weighted average of VSL is close to the selected central estimates.

(a) Adult Chronic Respiratory Disease

Viscusi et al. (1991) and Krupnick and Cropper (1992) conducted a set of survey to estimate WTP for reducing risks of developing chronic bronchitis respiratory disease. Respondents were asked for choice between risks of developing chronic bronchitis and higher costs of living. Based on the results of these studies and using the scale of severity for chronic bronchitis disease, it was estimated that the central value of an average chronic bronchitis case would be about $291,000, and the low and the high estimates would be $175,000 and $466,000, respectively.

(b) Respiratory Hospital Admissions

The economic value for respiratory hospital admissions is estimated from average hospitalization costs plus forgone wages and then adjusted by the ratio of WTP/COI. That is,

Central Estimate = [Forgone Wages + Hospital Costs] x [WTP/COI]

The average hospitalization cost for a given illness is derived by multiplying the resource intensity weight (RIW) for the illness by the average cost per unit of RIW, which is estimated at $2,505 in 1992 prices. This unit cost is inflated by health care consumer price index to 1994 prices at $2,609. The average length of stay for the treatment of respiratory disease is 5.7 days. With the assumption of the WTP/COI ratio of 2 to account for the pain, discomfort and loss of additional activity, the central estimate for the economic cost of the illness leading to respiratory hospital admissions is about $6,500 per admission in 1994 prices. The low and high estimates are simply assumed to be at a ± 50% from the central value.

(c) Cardiac Hospital Admissions

The average hospitalization cost for cardiac hospital admissions is also estimated by multiplying its RIW by the average cost per unit of RIW. Based on the results reported by Burnett et al. (1994, 1995) and supplemented by Dave Stieb (1995), the cost for cardiac hospital admissions per case is $3,394 in 1992 prices and the length of stay is 5.6 days. The cost is adjusted to $3,536 to reflect the 1994 price level. Again, with the WTP/CIO ratio of 2, one can obtain the central estimate of $8,300 in 1994 prices. Applying a ± 50% adjustment yields a low estimate of $4,200 and a high estimate of $12,500 per hospital admission.

(d) Emergency Room Visits

Based on the study by Rowe et al. (1986), the average cost of emergency room visits was US$90 in 1986 prices. This cost is then converted to Canadian dollars and adjusted to 1994 prices at $192. This cost together with the loss of one-day wage at $113 will yield $305 for COI. With the assumption of 2 for WTP/COI, one can arrive at the central estimate of $600 per emergency room visit in 1994 prices. Again, applying a ± 50% adjustment yields a low estimate of $300 and a high estimate of $900.

(e) Asthma Symptom Days

Based on the study by Rowe and Chestnut (1986), the WTP responses were positively associated with the baseline frequency of asthma symptoms. The values also depend upon the number of days with any symptoms. We estimate that the low, central and high values would be $18, $49, and $81, respectively.

(f) Restricted Activity Days

A restricted activity day (RAD) is a combination of complete and minor activity restrictions. The Health Interview Survey indicates that about 40% of all RADs are bed-disability days. However, another study by Ostro (1987) suggested that RADs associated with air pollution exposure may be less severe than all RADs and as a result, 20% of RADs due to air pollution are assumed due to bed-disability days.

Krupnick and Kopp (1988) studied the WTP estimates from survey respondents regarding the amount they would be willing to pay to avoid a day with minor symptoms and restricted activity days. It was estimated at $36 in 1994 prices. The weighted average of the value for severe and minor RADs can be calculated as follows:

Central Estimate = [0.20 x (Wage) x (WTP/CIO)] + [0.80 x 36]

The central estimate for RADs is $74 in 1994 prices. Applying a ± 50% results in a low and high estimate at $37 and $111, respectively.

(g) Acute Respiratory Symptoms Days

Based on the studies by Loehman et al. (1979) and Tolley et al. (1986), we obtain the estimates of WTP, ranging from $7 to $21 in 1994 prices, to avoid a day with a single minor respiratory symptom such as head congestion or coughing. The central estimate, $14, is the simple average of the low and high estimates.

(h) Child Lower Respiratory Disease

The value of child lower respiratory disease is estimated from the cost-of-illness approach for bronchitis obtained from the study in the United States by Krupnick and Cropper (1989). The average annual medical treatment cost was US$42 in 1977 prices. This is converted to Canadian dollars and inflated to 1994 prices with the medical consumer price index and then multiplied by the WTP/COI ratio of 2 to account for potential pain and loss of other activities. The central estimate for the child lower respiratory disease is about $360 in 1994 prices. Applying a ± 50% adjustment results in a low estimate of $180 and a high estimate of $540. These estimates are conservative because loss of forgone wages by the caregiver is not accounted for during the time children are ill.

Other health effects such as visibility impacts may be important, but they are not quantified because of uncertainties associated with the economic values of people's viewing activities.

5.2.4 Measurement of Gross Health Benefits

With the multiplication of the central estimates of the monetary valuation for each of the health effects and the annual frequency of the corresponding occurrences, we can obtain the annual monetary value of the avoided health effects over the 20-year study period. If the values are inflated by GDP deflator to the year of 2000 when the capital expenditures incurred, the total health benefits for Scenario 1, for example, would increase from $201.5 million in 2001 to $284.0 million.

Considering the profile of the benefits over time for the most stringent case, Scenario 6, the total benefits would increase from $484.8 million in 2001 to $750.5 million in 2020. The size of benefits is directly related to the reductions of the sulphur content of fuels. The main reasons for having high benefits associated with the largest amount of sulphur removed from fuels is due to the fact the health benefits accrue to individuals across the country while for the less stringent cases, only the areas with very high sulphur at the present time are affected.

It should be noted that of all health benefits, the benefits generated from avoiding premature mortality risks account for more than 75% of the total benefits. This is because the value associated with the single premature mortality is much greater than the value of any other morbidity effect. Although the number of morbidity effects is far greater than the number of deaths, it is the total value of the reduction in mortality that dominates the overall value of benefits.

There are also unquantifiable benefits in this situation. Many uncertainties are also involved in estimating the response of human health to the reduction of sulphur in gasoline and diesel fuels. These will be dealt with in the risk analysis and the main findings are also presented in accounting tables.

5.3 Net Health Benefits for Canada

The objective of the cost-benefit analysis is to estimate the net impact of a regulatory policy. The previous sections dealt with the incremental gross benefits of each of the "with" and "without" regulatory policy. In order to derive the net economic benefits, we have to integrate the gross benefits with the incremental costs for each of the alternative scenarios.

The costs refer to the incremental cost of resources used as a consequence of implementing the regulatory policy. This includes the compliance costs incurred by the private sector and the administrative costs incurred by government as outlined in Section 5.1. The compliance costs are the costs incurred by businesses in order to meet the level of sulphur in gasoline set down by the regulation. They include capital expenditures as well as operating and maintenance costs.

To meet the requirements specified by regulations, there are likely to have some refineries that should be shut down rather than making the necessary investment in alternative scenarios. Based on the analysis undertaken by the Cost and Competitiveness Panel, a number of refineries could be closed down including one for scenario 3, three for scenario 4, and four for scenarios 5 and 6. The costs of liquidating these facilities are part of the cost. On the other hand, the economic value of the assets when liquidated should be counted as part of the benefit. However, no data are available for either the cost of cleaning the site or the value of liquidated assets. For all intents and purposes, they are assumed to be offset each other.

The private costs may not be the same as resource costs for society as a whole. In the cost-benefit analysis, all private costs must be measured in terms of their economic opportunity costs. In this case, capital costs include equipment purchases and construction services. Using a rule of thumb, about half of the capital cost is spent on either equipment or construction services. All equipment is tradable goods. Their economic cost is measured by their financial costs net of import tariffs. In this case study, all the equipments are assumed to not be subject to import duty and hence their economic cost is the same as the financial cost.

The construction services would involve erection cranes, concrete footings, welding, pressure testing, and the assembly of the equipment. These workers are mostly tech school graduates and are highly paid and mobile. They are generally in short supply in the labor market. The social opportunity cost of these workers is about the same as the wage rates received from refineries. Thus, no adjustment is needed for the economic opportunity cost of these workers. In the case of operating costs, they are mainly fuels and no adjustment is required for this traded commodity.

As mentioned earlier, some refineries may be shut down because of their advantage. It is not cost-effective to upgrade them to meet the new standards. A typical refinery would employ about 300 to 350 workers. When refineries are closed, these workers will be laid off. They are likely to either take early retirement or because of their relatively high skills will find alternative jobs rather quickly and hence, little net economic loss would occur. For the purpose of this analysis, we assume that these workers earn on average $67,000 in 2000 prices per year before layoff and also find alternative jobs in the refinery industry at the same amount of income. Suppose the percentage of the layoff workers who cannot find jobs is 15% in the first year, 7.5% in the second year, and from the third year on nobody is unemployed. This is likely to be a high estimate of the income loss given the shortage of workers in this sector. It implies that the social cost or the private income loss suffered by these layoff workers, expressed in the present value of the losses, is approximately 20.3% of the total annual wage earnings of the entire layoff workers, using the 8 percent discount rate.[15] This would represent the largest amount of the economic loss due to the closure of refinery and layoff of workers. As the Cost and Competitiveness Assessment Panel indicated, one refinery for scenario 3, three for scenario 4, and four for scenarios 5 and 6 would be threatened and likely to be closed.[16] Suppose they are all closed as expected and each refinery employs 350 workers, the social costs of the potential job losses for this worse case scenario are estimated and included in the evaluation of the scenarios.[17]

Additionally, in order to enforce the regulations, governments will incur annual costs of approximately $60,000 in administration, monitoring, and enforcement. These additional costs should be counted as part of the economic cost in the cost-benefit analysis. These administration costs, however, are considered having marginal impacts for all scenarios. For all intents and purposes, it can be ignored in the analysis.

The annual net benefits can be estimated over the 20-year period and discounted by the economic opportunity cost of capital in order to derive the net present value of each of the six alternative scenarios under consideration. The economic discount rate has recently been estimated to be 8 percent real for Canada.[18] Using the 8 percent rate, the net present values of net economic benefits for all scenarios are presented in Table 8. The results indicate that reducing sulphur in gasoline for any scenario under consideration would generate substantial net health benefits or well-being for Canadians as a whole, ranging from $1,810 million to $2,663 million.

[15] This is equal to the sum of 15%/1.08 and $7.5\%/(1.08)^2$.

[16] See Purvin & Gertz, Inc., *Phase III: Competitiveness and Viability Impact on Canadian Refining Industry of Investments to Reduce Sulphur in Gasoline and Diesel*, report prepared for Cost and Competitiveness Assessment Panel, (May 1997), p. II-17.

[17] The concepts used in this analysis can be found in Graham Glenday and Glenn P. Jenkins, "Industrial Dislocation and the Private Cost of Labor Adjustment", *Contemporary Policy Issues*, Number 4, (January 1984).

[18] The social discount rate or the economic opportunity cost of capital is estimated as a weighted average of the rate of return on displaced private-sector investment and the rate of return to domestic and foreign savings. See Privy Council Office, Government of Canada, *Canadian Regulatory Analysis Guide*, (March 2006).

Table 8
Net Economic Benefits for Alternative Scenarios
(millions of 2000 prices)

Scenario	Net Present Value @8%
Scenario 1: 360 ppm	1,809.2
Scenario 2: 250 ppm	2,104.4
Scenario 3: 200 ppm	2,416.9
Scenario 4: 150 ppm	2,576.4
Scenario 5: 100 ppm	2,663.1
Scenario 6: 30 ppm	2,414.1

There are omissions and uncertainties that cannot be quantified and included in the analysis. These items are provided below for consideration when decision-makers make their final decision.

First, the above analysis assumes that all health effects of air pollution can be indexed to the level of sulphates. This may understate the effects since other pollutants such as sulphur dioxides, carbon dioxides and nitrogen dioxides will also be reduced and may have independent health effects.

Second, when the atmospheric models simulate the impact for each of seven cities, it does not consider the long-range transport of air pollution. This will understate the health benefits of reducing sulphur contents especially in the area of the Quebec-Windsor corridor.

Third, some estimates of the concentration response function are based on studies conducted in other countries. In addition, the future health effects are calculated based on 1995 population age structure which may change in the future. These factors may create some uncertainty.

Fourth, the wide range of the value of statistical life has the most significant implications of the monetary valuation of health effects. The age adjustment of VSL for seniors may compound the issue and should be interpreted with caution.

Fifth, other impacts on agriculture, forest, fishing, etc. are not quantified although the impacts may be significant.

With the above caveats, we are still confident that each of the alternative scenarios will contribute substantial net benefits to the well-being of Canadians.

5.4 Dealing with Uncertainty and Risk

The above results represent the most likely and reliable estimates of various variables that affect the changes in emissions that in turn, determine the magnitudes of the health effects. The estimation of the values of the health benefits are also affected by the measurement in monetary terms of each of the avoided health effects. From the evidences of various studies on the subject, one can see that there still is risk and uncertainty in the scientific research concerning the exact impact of any change in the emissions on the quality of air as well as the effect of the quality of air on human health. The results are further affected by some uncertainty in the estimated values for each of the identified mortality and morbidity health effects as presented in the literature. This uncertainty and risk is further compounded as the effects need to be projected over a 20-year study period with additional assumptions being made of the conditions that are likely to exist with and without the regulation in the future.

Sensitivity analysis is conducted to identify variables that may have a major impact on the net benefits of the regulations. For a variable to be classified as being a source of risk for the outcome of a regulatory intervention must have a significant impact on the outcomes and its value must also be uncertain in nature. As a result, the risk variables selected for this case study include the capital costs of retrofitting the refineries, the changes in operating costs due to the production of low sulphur in gasoline, the response of premature mortality to sulphate concentrations, and the value of a statistical life.

The range of uncertainty for capital costs obtained from the engineering studies is $\pm$ 40% and for operating costs, it is $\pm$ 25%. We use a normal distribution to account for the disturbances of these costs in the risk analysis. Therefore, with the mean value of 0%, the standard deviation will be 13% for the capital costs and 8% for the operating costs.

The impact of emissions on premature mortality is the most important variable affecting the outcome and the net benefits of the regulations. The estimated percentage response of premature mortality to sulphates by the atmospheric model, according to the research of the scientists and health experts is 1.14×10^{-5}, 2.54×10^{-5}, and 5.74×10^{-5} for low, central, and high estimates with the corresponding probability of 22%, 67%, and 11%. We use a step distribution and these probabilities to the model of the risk analysis. This was based on a consensus of the panel.

In the case of the value of statistical life, the range of estimates in the scientific literature is wide from $1.0 million to more than $12 million. However, based on the conclusion reached by the health experts, the age-weighted average VSL is $2.4 million, $4.0 million, and $7.9 million for the low, central, and high estimates with the probability of occurring of 33%, 50%, and 17%. Like the effect on premature mortality, we use a step distribution to account for the disturbances of this variable.

Monte Carlo simulations are used in which the values of uncertain variables are selected according to the ranges of their possible values and the specified probability distributions. For the purposes of this analysis, we select two scenarios -- 4 and 6 -- and perform 10,000 trial runs. The results of the risk analysis are summarized in Table 9. The expected value of the net present value of net benefits for each scenario is very close to the value of the respective determinate cases. For example, the expected net benefits for Scenario 6, where the sulphur content is lowered to 30 ppm, are $2,401.8 million, as compared to the deterministic value of $2,414.1 million. Moreover, the net benefits of the outcomes for all 10,000 runs range from $137.2 million to $5,410.9 million. This implies there is zero probability of getting the negative net benefit.

Table 9
Risk Analysis Results for Selected Scenarios
(millions of 2000 prices)

Statistical Values	Scenarios	
	Scenario 4: 150 ppm	Scenario 6: 30 ppm
Determinate Case	2,576.4	2,414.1
Risk Analysis:		
Range	1,096.4 to 4,861.0	137.2 to 5,410.9
Mean Value	2,567.4	2,401.8
Median Value	2,528.8	2,357.1
Standard Deviation	480.4	667.5
Coefficient of Variation	18.71%	27.79%

5.5 Impacts on Stakeholders

A stakeholder analysis is conducted to identify the impact on the sub-population of the regulations and to examine how much they would gain or lose as a result of the implementation of the regulations. In this case, the stakeholders will include oil refineries that have to comply with the regulations, refinery workers who are laid off, individuals and households who will receive benefits because of avoided health effects, provincial governments who are responsible for the health systems and financing the public health of their respective provinces in Canada, and the federal government who is responsible for monitoring and enforcing the regulations.

For each of the alternative scenarios, the oil refiners are required to comply with the regulation in the reduction of the sulphur content of gasoline. It is likely some of them will have to incur capital expenditures on equipment and construction services in 2000 and annual operating costs from 2001 to 2020. A penalty will be imposed if compliance with the regulation is not reached. That being said, refiners will attempt to recover their costs from consumers via an increase in prices of gasoline. Based on the assessment by the Cost and Competitiveness Panel, the price of gasoline is expected to increase between 0.5 and 1.0 cent per litre. This is a complicated issue, depending upon the supply and demand conditions of the market. Given that the elasticity of demand is considerably less elastic than the supply of gasoline to the market, we expect that three-quarters of the costs would be passed forward in the higher prices of fuels. In other words, refiners would recover most of the cost from their costumers and bear not more than one-quarter of the incremental costs themselves.

Individuals or households are the main beneficiaries of these measures because having cleaner air lowers the risks of premature mortality and morbidity. Although the costs of complying the regulatory policy may initially be paid for by the refiners, overtime a significant portion would be shifted to consumers. This additional price increase in fuels will offset some of the gross health benefits gained by individuals or households.

The engineering study group in the Cost and Competitiveness Panel indicted that some refineries could be shut down as a result of high compliance costs for certain scenarios. For example, one refinery for scenario 3, three for scenario 4, and four for scenarios 5 and 6 may be closed. As a typical refinery employs about 350 workers, several hundred up to a couple of thousand jobs would be laid off, depending upon the scenarios. As mentioned earlier, we assume that in this case study, the closures would occur and most of these layoff workers are expected to find alternative jobs quickly due to their high level of skills and the overall labor market shortages of these types of workers. Only 15% of the workers are not expected to find jobs in the first year and 7.5% in the second year after the refineries are shut down. Hence, there are some economic costs that would be incurred by some workers employed in the existing refineries.

Furthermore, some of the avoided health effects will lower the number of hospital admissions and visits that would reduce costs in hospital and in turn, save money for provincial governments. In other words, part of the WTP for the reduced incidence of illness in the case of respiratory hospital admissions, cardiac hospital admissions, and emergency room visits should be counted as cost savings by the provincial governments. This can be calculated directly from the portion of the WTP that is identified as hospital costs.

The distribution of regulation net benefits for each scenario is presented in Table 10. It is clear that individuals and consumers are the recipients of most of the benefits in all scenarios. Provincial governments also benefit a small amount because of the reduction of the number of hospital admissions and other associated costs. The federal government will incur some administrative costs to monitor and enforce the regulations. The shareholders of the companies owning the refineries bear the costs of complying with the regulations. However, a significant amount of the costs would be passed forward to consumers in terms of higher prices of gasoline. Finally, there are some economic costs of adjustment suffered by the layoff workers as a result of refinery closures.

Table 10
Present Value of Net benefits by Stakeholder and by Scenario
(millions of 2000 prices)

Scenario	Refiners	Refinery Workers	Consumers and Individuals	Governments		Total
				Provincial	Federal	
Scenario 1: 360 ppm	(111.9)	0	1,916.4	5.3	(0.6)	1,809.2
Scenario 2: 250 ppm	(260.1)	0	2,357.8	7.3	(0.6)	2,104.4
Scenario 3: 200 ppm	(326.4)	(4.8)	2,739.9	8.8	(0.6)	2,416.9
Scenario 4: 150 ppm	(426.1)	(14.3)	3,007.4	10.0	(0.6)	2,576.4
Scenario 5: 100 ppm	(553.8)	(19.1)	3,225.1	11.5	(0.6)	2,663.1
Scenario 6: 30 ppm	(801.9)	(19.1)	3,222.6	13.0	(0.6)	2,414.1

The impact of reducing sulphur content also varies from city to city. This is especially evident for Toronto. Because of its large population, its intensity of vehicles, and high current levels of air pollution, it is benefiting most from the reduction of sulphur in gasoline. However, residents in the rest of the country also benefit.

5.6 Conclusion

The above cost-benefit analysis has confirmed that reductions of sulphur in gasoline for all of the six alternative scenarios will generate a substantial amount of health benefits to Canadians, ranging from $1.8 billion to $2.7 billion in 2000 prices. The net present values are calculated using a real discount rate of eight percent. The risk analysis also suggests that in the case of reducing the level of sulphur to the level of either 150 ppm or 30 ppm, there is zero probability of getting a negative economic benefit. The stakeholder analysis indicates that the Canadian refiners can pass a significant amount of costs forward to final consumers in the higher prices of fuels, hence, their competitiveness should not be significantly affected.

The most stringent scenario 6 of lowering sulphur in gasoline to 30 ppm would not only generate a considerable amount of the economic benefits ($2.4 billion in 2000 prices) but also have a number of benefits that are not easily taken into account in the quantitative analysis. First, requiring the lowest sulphur level in gasoline will make it worthwhile for the research and development to go ahead for the development of vehicle pollution control systems that function more efficiently. Second, low sulphur content in the gasoline will make it less costly for the automobile industry to develop more fuel efficient motor vehicles. In this way, the regulation that minimizes the level of sulphur in gasoline will help Canada control greenhouse gas emissions in the future.

We can see from Table 8 that the net present value of scenario 6, before including these additional unquantifiable effects, would have a slightly lower net present value than scenarios 4 and 5. However, scenario 6 will create a suitable regulatory environment for the greatest pursuit of research and development by the automobile industry to make further improvements in pollution control devises on automobiles. Given these conditions, it is our judgment that scenario 6 which lowers the sulphur level in gasoline to 30 ppm is the preferred option to be recommended for implementation. This option lowers the risk of a more rapid deterioration of the air quality in the future.

VI. Preparing an Accounting Table

After completing the analysis, it is useful to summarize the results in tabular form as is shown in Table 11A.

6.1 Cost-Benefit Analysis

Deterministic Case

Table 11A provides the estimates of the annual incremental benefits and costs of the regulations over the study period as compared to the baseline scenario for each of the six alternative scenarios. The amounts are undiscounted values and expressed in 2000 prices. The stream of annual benefits and costs are discounted at 8 percent real to obtain the present value in year 2000. The annualized values of the net benefits over the impact period are also calculated.

Since the most important element in this case study is the impact on the various health effects, the number of health effects by health category are presented for each of the alternative scenarios. For illustrative purposes, we provide the avoided health effects by category for scenario 6. They are displayed in Table 12. The table also shows the estimated value of each health effect expressed in 2000 prices.

Dealing with Risk/Uncertainty

In this case, there are risk and uncertainty in scientific research about the impact of change in emissions on the quality of air as well as the effect of the quality of air on human health. In addition, there are also uncertainties with respect to the value of each of the identified health effects. For the purpose of illustration, two scenarios are presented here. Four risk variables have been identified and their probability distributions are also determined as shown in Table 13. Using Monte Carlo simulations, the expected net benefits, along with other statistic values, are all presented in Table 13.

Several items of health and environmental effects are not quantified due to the model used and the current knowledge of the areas. These items are listed below and presented in Table 11B for consideration by decision-makers:

First, the impacts of pollutants other than sulphate on air are not accounted for.
Second, the impact of the long-range transport of air pollution is not taken into account.
Third, the impacts on agriculture, forest and fishing are not properly assessed and quantified.
Fourth, potential visibility changes are not assessed.
Fifth, the positive impacts on controlling greenhouse gas emissions are not accounted for.

6.2 Stakeholder Analysis

This section provides the impacts of the regulations on various stakeholders, including oil refiners, refinery workers, consumers and individuals, and governments. In order to comply with the regulations, some refiners have to incur capital investment in year 2000 on equipment and constructions services and then operating costs from year 2001 on. However, a significant amount of these costs would be expected to be shifted forward to consumers in higher prices of gasoline. This negative impact on consumers will be offset by the substantial benefits received as a result of avoided health effects. Some refinery workers will be laid off as a result of closure of refineries. These workers would suffer for a temporary work adjustment. Due to lower number of hospital admissions and visits, provincial governments would reduce some budget on hospital spending. These impacts are presented in Table 14 for each of the alternative scenarios.

Table 11A

Annual Incremental Benefits and Costs for Alternative Scenarios (

	Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006
Scenario 1: 360 ppm							
Benefits	-	201.48	205.15	208.90	212.70	216.58	220.53
Costs	192.04	26.10	26.10	26.10	26.10	26.10	26.10
Net Benefits	(192.04)	175.38	179.06	182.80	186.61	190.49	194.43
Scenario 2: 250 ppm							
Benefits	-	273.87	279.77	285.79	219.95	298.23	304.66
Costs	309.58	66.24	66.24	66.24	66.24	66.24	66.24
Net Benefits	(309.58)	207.63	213.53	219.55	225.71	231.99	238.42
Scenario 3: 200 ppm							
Benefits	-	321.15	328.52	336.06	343.78	351.67	359.74
Costs	634.69	71.93	70.17	68.41	68.41	68.41	68.41
Net Benefits	(634.69)	249.22	258.35	267.65	275.37	283.26	291.33
Scenario 4: 150 ppm							
Benefits	-	375.30	383.21	391.29	399.54	407.96	416.56
Costs	756.21	107.17	101.90	96.62	96.62	96.62	96.62
Net Benefits	(756.21)	268.13	281.31	294.67	302.92	311.34	319.94
Scenario 5: 100 ppm							
Benefits	-	430.02	438.80	447.77	456.92	466.25	475.78
Costs	968.86	141.06	134.04	127.00	127.00	127.00	127.00
Net Benefits	(968.86)	288.95	304.77	320.77	329.92	339.26	348.78
Scenario 6: 30 ppm							
Benefits	-	484.82	496.10	507.64	519.45	531.53	543.90
Costs	1,939.98	143.24	136.21	129.17	129.17	129.17	129.17
Net Benefits	(1,939.98)	341.58	359.89	378.47	390.28	402.37	414.73

Table 11B

A list of Unquantifiable Health and Environ

There are potential health and environmental effects in this case th
have significant impact on decision-making. These items are listed

1. In this study, we have used sulphate as the index pollutant fo
   However, other pollutants such as sulphur dioxides, carbon d
   will also be reduced and may have independent health effects
   other than sulphate on air quality are not accounted for, henc
   may well be understated.
2. The total net benefits of lowering the sulphur in gasoline are
   measurement derived from the seven cities. This approach wi
   negative impact caused by the long-range transport of air pol
3. The impact of reduction of sulphur in gasoline on crop produ
   from limited studies. Similarly, studies have identified that a
   roots and will cause disruption to reproduction or regeneratio
   evidence has yet supported this argument. Hence, no quantifi
4. In the case of the environment, there may be potential visibil
   residential properties, work places, national parks, wildernes

visibility changes may be important but are difficult to measu
are therefore not quantified in this study.

5. Lowering the sulphur content of the gasoline will make it les
industry to develop more fuel efficient motor vehicles. In this
minimizes the level of sulphur in the gasoline will help Cana
in the future. This effect is not quantified.

Table 12

Reductions of Avoided Health Effects for Scenario
(number of events)

Health Effects	Value per Event		Year 2001	Year 2002	Year 2003	Year 2004	Year 2005	Year 2006
	($ in 2000 prices)		(number of e					
Premature Mortality	4,369,000		84	86	88	90	92	94
Chronic Respiratory Disease	323,857		302	310	317	324	332	339
Respiratory Hospital Admissions	7218		52	54	55	56	57	59
Cardiac Hospital Admissions	9250		43	44	45	46	47	48
Emergency Room Visits	677		270	277	283	290	297	304
Asthma Symptoms Days	54		131,402	134,465	137,599	140,806	144,087	147,446
Restricted Activity Days	82		63,721	65,205	66,724	68,278	69,868	71,495
Acute Respiratory Symptoms	16		438,197	438,391	458,822	469,496	480,418	491,594
Child Lower respiratory Illness	399		3,683	3,771	3,860	3,953	4,047	4,143

Table 13

Risk Analysis Results

Category	Parameters	Range
Risk Variables	Variable 1: Capital Costs	± 40%
	Variable 2: Operating Costs	± 25%
	Variable 3: Mortality Response	Low Estimate: 0.17% (22%); Central Estimate: 0.38% (67% Hugh Estimate: 0.85% (11%)
	Variable 4: Value of Statistical life	Low Estimate: $2.4 million (Central Estimate: $4.0 millio High Estimate: $7.9 million (
Analytical Results	Scenarios Analyzed	Statistical Re
Monte Carlo Simulation Results	Scenario 4: 150 ppm Sulphur in Gasoline	Mean: $2,567.4 million; Median: $2,528.8 million; Range: $1,096.4 million to $4 Coefficient of Variation: 18.7
	Scenario 6: 30 ppm Sulphur in Gasoline	Mean: $2,401.8 million; Median: $2,357.1 million; Range: $137.2 million to $5,4 Coefficient of Variation: 27.7

Table 14
Stakeholder Impacts
(millions of 2000 prices)

Scenarios	Refiners			Refiner Workers	Consumers and Indivi	
	Initial Costs	Costs Shifted Forward	Net Impact		Payments for Higher Fuel Prices	Gross Health Benefits
Scenario 1: 360 ppm	(447.7)	335.8	(111.9)	0	(335.8)	2,252.2
Scenario 2: 250 ppm	(1,040.4)	780.3	(260.1)	0	(780.3)	3,138.1
Scenario 3: 200 ppm	(1,305.8)	979.3	(326.4)	(4.8)	(979.3)	3,719.3
Scenario 4: 150 ppm	(1,704.3)	1,278.2	(426.1)	(14.3)	(1,278.2)	4,285.6
Scenario 5: 100 ppm	(2,215.2)	1,661.4	(553.8)	(19.1)	(1,661.4)	4,886.5
Scenario 6: 30 ppm	(3,207.5)	2,405.6	(801.9)	(19.1)	(2,405.6)	5,628.2

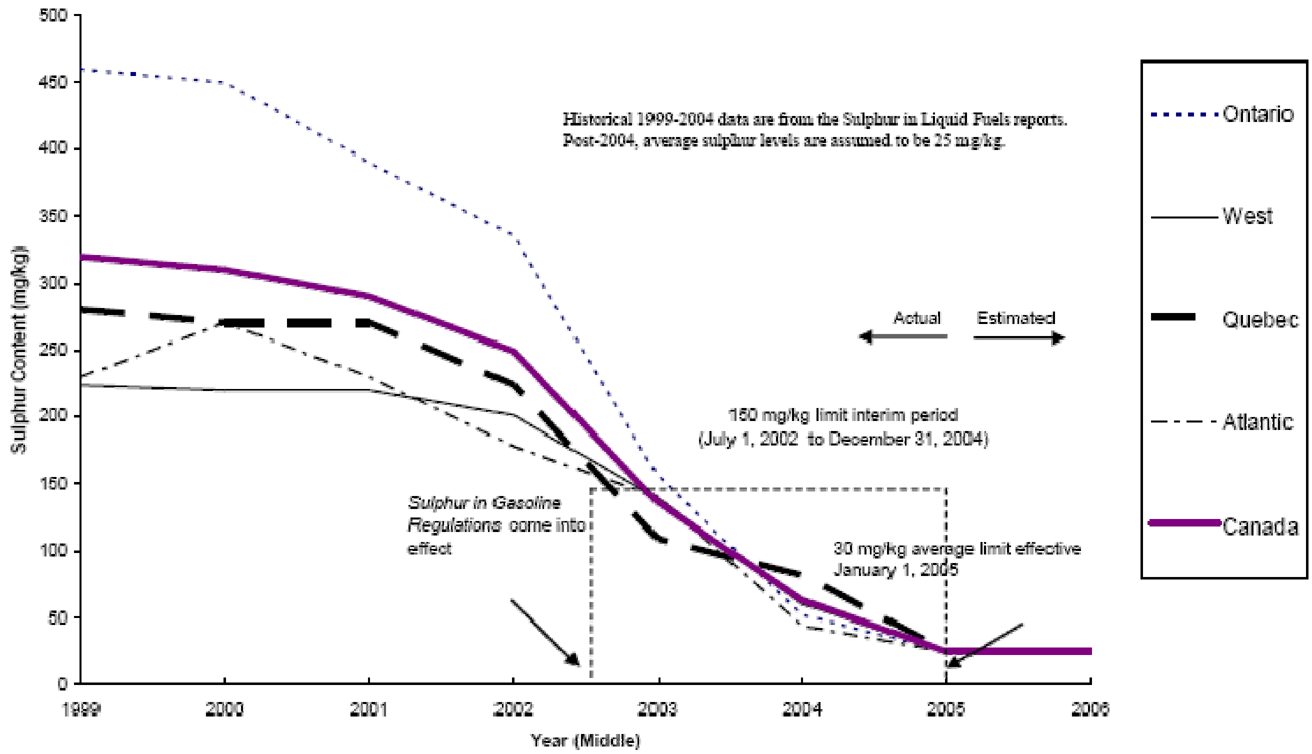
VII. Ex-Post Assessment

The sulphur in Gasoline Regulations was set at an average level of 30 parts per million with a never-to-be-exceeded maximum of 80 ppm and implemented beginning January 1, 2005. As an interim step for the first 30 months, the level of sulphur in gasoline limited to 150 ppm with a level never to exceed 200 ppm at any time starting July 1, 2002 until the end of 2004. In other words, the regulation has been in place for more than five and a half years, and has been fully implemented for two years.

Health Canada has been monitoring the levels of sulphur content in gasoline over time. This is shown by region and by national as a whole in Figure 1. As expected, the levels of sulphur in gasoline have followed closely those set by the Regulations. These results show a significant improvement in the air quality in Canada, even though a longer period of observation may be needed.

On another front, Environment Canada has indicated that with the most stringent scenario of lowering sulphur in gasoline, there has been no closure of any refineries. In addition, some refineries such as those owned by Imperial Oil have skipped the phased-in approach and moved directly to the sulphur level of 30 ppm. This appears to suggest that the Canadian refineries had rearranged their operations and managed well in their compliance with the Regulations.

Figure 1: National Trend of Sulphur Content in Gasoline (1999-2006)



Sources: Elizabeth Escorihuela, Taryn Adams and Sean Poulter, "Sulphur in Liquid Fuels, 2004", report prepared for Environment Canada, (October 2005).

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