Cost Benefit Analysis:

Replacing

Ontario's Coal-Fired

Electricity Generation

Prepared for
Ontario Ministry of Energy

Prepared by
DSS Management Consultants Inc.
RWDI Air Inc.

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I. EXECUTIVE SUMMARY

Introduction

This report documents the methodology, data and results of an independent cost-benefit analysis (CBA) of the financial costs and health and environmental damages associated with four electricity generation scenarios. These scenarios cover a range of electricity generation alternatives for replacing the electricity produced by the province's coal-fired generation facilities. The results of this study provide an estimation of the costs and benefits of some of the policy directions available to the government of Ontario with respect to replacing the coal-fired generation facilities.

Four scenarios were identified by the Ministry of Energy, namely:

- **Scenario 1 – Base Case** (the status quo, continue operating the coal-fired generation facilities within the current regulatory regime[1]),
- **Scenario 2 – All Gas** (produce all of the replacement electricity through gas generation facilities constructed for this purpose alone),
- **Scenario 3 – Nuclear/Gas** (produce all of the replacement electricity through a combination of refurbished nuclear and new gas generation facilities constructed for this purpose alone), and
- **Scenario 4 – Stringent Controls** (continue operating the coal-fired generation facilities but install new emission control technology so that the best available control technology is in place).

The first step in this CBA was to estimate the financial costs (i.e., capital, operating, maintenance and fuel costs) of each scenario. The next step involved air quality modelling using projected emission profiles for each scenario. Next the health and environmental impacts of each scenario were estimated. Finally, the corresponding monetary value of these impacts was estimated. By summing the financial costs and monetary health and environmental damages, the total cost of generation for each scenario was estimated. The net benefit for each of the three scenarios relative to the base case was calculated by taking the difference in the total cost of generation.

Total Cost of Generation

Table I-1 below shows the total cost of electricity generation (i.e., financial costs plus health and environmental damages) for each scenario. This total cost of generation represents the minimum average amount that society must be willing to pay for the generation of this electricity to be worthwhile.

The total costs of generation are sensitive to the methodology used to estimate the risk of premature mortality (i.e., the number of premature deaths) attributable to air pollutant emissions from electricity generation facilities. Table I-1 includes total costs of generation derived both using long-term premature mortality risk factors and acute (i.e., short-term) premature mortality risk factors; the values estimated using the latter factors are shown in brackets.

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[1] Ontario Regulation 397 has established emissions caps for the province's coal-fired generation facilities. These emission caps were assumed to be met in the Base Case and this is reflected in the electricity generation output and emission profiles for this scenario.

Table I-1 Total Cost of Generation

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Total Present Value (2007-2026) ($Billions)	**$49** ($21)[a]	**$29** ($26)	**$22** ($18)	**$32** ($21)
Annualised Costs ($Millions)	**$4,377** ($1,836)	**$2,605** ($2,279)	**$1,942** ($1,635)	**$2,802** ($1,895)
Levelised Costs ($/MWh)	**$164** ($69)	**$98** ($86)	**$72** ($61)	**$105** ($71)
Health and Environmental Proportion	**77%** (46%)	**20%** (9%)	**21%** (6%)	**51%** (28%)
a: Values shown in brackets are based on acute premature mortality damage estimates.				

These values based on acute premature mortality risk factors are shown for comparison purposes only. The total costs of generation are consistently lower with the acute premature mortality risk factors since only a portion of the full risk of premature mortality is reflected in these costs.

The average annual total cost of generation ranges from a low with Scenario 3 (Nuclear/Gas) of $2.0 billion to a high of $4.4 billion with Scenario 1 (Base Case). The average annual costs of generation for Scenarios 2 (All Gas) and 4 (Stringent Controls) are similar and are about 30-45% greater than the cost for Scenario 3 (Nuclear/Gas) with average annual total costs in the range of $2.6 to $2.8 billion.

The corresponding levelised cost estimates are more directly comparable to the electricity generation costs with which many are familiar. The financial costs of Scenario 1 (Base Case) represent a levelised cost of $37/MWh. However, this cost does not include external costs associated with health and environmental damages. When these costs are added in, the total cost of coal-fired generation rises to $164/MWh. In total, health and environmental costs account for 77% of the total cost of generation with Scenario 1 (Base Case).

With Scenario 2 (All Gas), a much greater portion of the costs are associated with financial costs. In this case, the financial costs of generation result in a levelised cost of $78/MWh. On the other hand, the external health and environmental costs are considerably less with Scenario 2 resulting in a levelised total cost of generation in the order of $98/MWh. Similarly for Scenario 3 (Nuclear/Gas) the financial cost is $57/MWh increasing to $72/MWh when the external health and environmental costs are added.

These different proportions among the component costs of generation highlight a key difference among the scenarios. With Scenario 1 (Base Case) and to a lesser extent, Scenario 4 (Stringent

Controls), lower financial costs are traded off against higher health and environmental damages. The opposite is the case with Scenarios 2 (All Gas) and 3 (Nuclear/Gas).

Table I-2 shows the net benefits of the three alternative scenarios relative to the Base Case (i.e., Scenario 1). The comparable net benefit estimates using the acute premature mortality risk factors are shown in brackets for comparison purposes.

The annual average net benefits for each of the three scenarios are $1.8 billion for Scenario 2 (All Gas), $2.4 billion for Scenario 3 (Nuclear/Gas) and $1.6 billion for Scenario 4 (Stringent Controls). On the basis of estimated net benefit, Scenario 3 (Nuclear/Gas) is expected to yield the highest return of the four scenarios analysed.

If only the economic damages associated with acute premature mortality risks are used to estimate net benefit, both Scenarios 2 (All Gas) and 4 (Stringent Controls) would yield annual net losses relative to the Base Case. Scenario 3 (Nuclear/Gas) would yield a positive annual net benefit of $200 million per year.

Table I-2 Estimated Net Benefits for Each Scenario

	SCENARIO		
	2 All Gas	**3 Nuclear/ Gas**	**4 Stringent Controls**
Present Value ($Billions)	**$20** (-$5.0)[a]	**$28** ($2.3)	**$18** (-$0.7)
Annualised ($Millions)	**$1,772** (-$443)	**$2,435** ($201)	**$1,575** (-$59)
Levelised ($/MWh)	**$67** (-$16.7)	**$91** ($7.5)	**$59** (-$2.2)

a: Values shown in brackets are based on acute premature mortality damage estimates.

Following are further details on how these results were derived.

Air Pollution Modelling

The first step in the damages assessment portion of the CBA was to generate air quality forecasts. These forecasts are based on expected emissions of air pollutants from each electricity generation alternative. Total emissions vary significantly among the scenarios. An atmospheric pollutant transport, dispersion and chemical transformation model (CALPUFF) was used to produce estimates of the impact of each scenario on local air quality conditions.

Closing the existing coal-fired generation facilities is expected to improve overall air quality in Ontario, but other pollution sources (e.g., transboundary air pollution, vehicle emissions) will continue to create hazardous air quality conditions. The greatest improvement in air quality will generally be realised immediately downwind of the coal-fired generation facilities. On the other hand, building new gas generation facilities would also cause some air quality impacts, although much less so than from coal-fired generation. Determining the health, environmental and economic damages associated with these air pollution changes requires rigorous analysis using health and environmental impact modeling as has been done in this study.

Health Impacts

Table I-3 summarises the estimated annual average health impacts associated with each scenario. An average annual total of about 660 premature deaths, 920 hospital admissions, 1,090 emergency room visits and 331,000 minor illness cases could be avoided by switching from the Base Case (Scenario 1) to Nuclear/Gas (Scenario 3). Even so, emissions associated with Scenario 3 (Nuclear/Gas) are still expected to contribute to a total of 5 premature deaths, 12 hospital admissions, 15 emergency room visits and 2,500 minor illness cases per year. The health impacts of Scenario 2 (All Gas) are about double those with Scenario 3 (Nuclear/Gas) while the health impacts of Scenario 4 (Stringent Controls) are considerably greater than those associated with Scenario 3 (Nuclear/Gas) but are well below those with Scenario 1 (Base Case).

Table I-3 Summary of Annual Health Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Premature Deaths (Total)	**668**	**11**	**5**	**183**
Premature Deaths (Acute)	103	2	1	28
Hospital Admissions	**928**	**24**	**12**	**263**
Emergency Room Visits	**1,100**	**28**	**15**	**312**
Minor Illnesses	**333,660**	**5,410**	**2,460**	**91,360**

As noted previously, two premature mortality risk factors were used in this analysis. Previous air pollution health damage estimates for Ontario have been based on time-series risk factors that only capture acute (i.e., short-term) premature mortality risks. Long-term risks of exposure to air pollution have been derived from epidemiological studies using a cohort methodology. The cohort-based methodology has been used for estimating health risks associated with exposure to air pollution by the US EPA and other organisations concerned with the health effects of air pollution. The cohort-based risk factors are more appropriate for this type of public policy analysis since they capture more completely the negative effects of air pollution exposure. The premature mortality risk associated with short-term exposure to air pollution was included for comparison purposes only.

Estimates of premature deaths attributable to exposure to air pollution are often the source of much confusion. Expressing the results in terms of expected numbers of premature deaths is a simple way to communicate the change in risk of premature mortality that occurs when members of a population are exposed to a change in air quality. More accurately, what is being forecast is the average change in risk that each individual in the exposed population experiences with a change in air quality. Multiplying this change in risk by the number of people exposed leads to an estimate of the number of premature deaths attributable to a given change in air quality.

In actual fact, it is impossible to identify which specific deaths that occur over a given period of time are actually attributable to air pollution. Air pollution is a contributory factor in a multitude of deaths and is almost never the overriding or irrefutable single cause of death. This in no way implies that air pollution is not causing premature mortality among a great number of individuals. Instead, reporting the change in risk as the number of expected individual deaths is an easy way to communicate the damage. These concepts extend as well to the economic valuation of premature mortality.

The average annual health damages (Table I-4) range from a low of $0.4 billion for Scenario 3 (Nuclear/Gas) to a high of $3.0 billion for Scenario 1 (Base Case). In other words, implementing Scenario 3 would result in an annual average health benefit (i.e., avoided health damages) of $2.6 billion. Scenario 2 (All Gas) has slightly higher annual health followed by Scenario 4 (Stringent Controls) with $1.1 billion in damages.

Table I-4 Annualised Financial Costs and Health and Environmental Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Financial Costs	**$ 985** [a]	**$ 2,076**	**$ 1,529**	**$ 1,367**
Health Damages	**$3,020** ($479) [b]	**$388** ($62)	**$365** ($58)	**$1,079** ($172)
Environmental Damages	**$371**	**$141**	**$48**	**$356**
Total Cost of Generation	**$4,377** ($1,836)	**$2,605** ($2,279)	**$1,942** ($1,635)	**$2,802** ($1,895)

a: All values are expressed as annualised costs/damages in 2004$ Millions.
b: Values shown in brackets are based on acute premature mortality damage estimates.

As with the estimates of physical damages, the economic damages based on acute premature mortality risk factors are considerably less. The overall ordering of the scenarios in terms of total health damages, however, remains the same.

The monetary health damage estimates are dominated by the value of avoiding the risk of premature mortality. For this reason, considerable attention has been given to using the best available information on the value that Ontarians place on reducing such risks.

Environmental Damages

In addition to health damages, emissions from electricity generation cause environmental damages. This analysis includes economic damage estimates relating to the soiling of household materials, crop loss and greenhouse gas emissions.

The average annual environmental damages are presented in Table I-4 and range from a low of $48 million for Scenario 3 (Nuclear/Gas) in to a high of $371 million for Scenario 1 (Base Case). In other words, implementing Scenario 3 would result in an average annual benefit (i.e., avoided environmental damages) of $323 million.

The estimates of economic damages for environmental effects are dominated by the costs of greenhouse gas control and carbon sequestration (or permit purchasing depending on which is less expensive). For example, with Scenario 1 (Base Case), greenhouse gas costs comprise 94% of the total estimated environmental damages.

Financial Costs

Capital, operating, maintenance and fuel costs were derived based on data provided by the Ministry of Energy and Ontario Power Generation (Table I-4). These financial costs have been estimated over a 22-year time horizon (i.e., 2005 to 2026). Standard economic principles have been used to derive estimates of the total present value of these costs (expressed in 2004$), annualised cost (expressed as the average 2004$ cost per year) and levelised cost (expressed as the average 2004$/MWh cost).

The average annual financial costs vary from a low of $1.0 billion for Scenario 1 (Base Case) to a high of $2.1 billion for Scenario 2 (All Gas). The distribution of these costs varies among the scenarios with the financial costs of Scenarios 1 (Base Case) and 4 (Stringent Controls) being paid solely by Ontario Power Generation. With Scenario 2 (All Gas) and, to a lesser extent, with Scenario 3 (Nuclear/Gas), the costs are spread among a larger pool of generators. In both cases, however, the costs will be borne ultimately by ratepayers.

Uncertainty and Sensitivity Analysis

The estimation of these health and environmental damages and financial costs involves various assumptions and expectations concerning the accuracy of the information which has been used and how the future will unfold in terms of economic forces. A systematic and detailed examination of the influence of these expectations and assumptions on the estimated net benefits for the scenarios has been conducted. This examination involved using statistical methods and sensitivity analysis.

When the statistical confidence ranges associated with health risks were used in an uncertainty analysis, the estimated net benefit for Scenario 3 (Nuclear/Gas) varied by 50% (i.e., by about ± $1.2 billion in average annual net benefit). Likewise, various sensitivity analyses concluded that net benefit estimates were most sensitive to two parameters, namely, the social discount rate and the economic value people are willing to pay to reduce the risk of premature mortality from air pollution exposure. When combinations of parameters were varied strategically to favour one alternative or another, even larger ranges in net benefits were observed.

These analyses confirmed the robustness of the net benefits estimates associated with Scenario 3 (Nuclear/Gas) relative to the other scenarios. Scenario 3 (Nuclear/Gas) is expected to yield the greatest net benefit of the alternatives analysed under virtually all reasonable conditions.

Gaps and Limitations

Not all health and environmental damages have been included in this analysis. As well, the estimation methodologies used in this analysis have some known limitations. A review of these gaps and limitations has been presented. A qualitative assessment of their potential effects on the estimated net benefit of each scenario has been prepared. These gaps and limitations need to be carefully considered when interpreting the results of this analysis.

Recommendations for Further Analysis

Recommendations for further analysis have been included, namely:

- Health and environmental damages associated with nuclear power generation should be included in future analyses.

- Additional scenarios should be analysed involving alternative proportions of nuclear, gas, renewable and other electricity generation options.
- The effects on net benefit estimates of delays in bringing new capacity on line should be analysed.
- Further analysis of the scenarios should be undertaken incorporating the effects of expected electricity market dynamics.

Conclusion

The results of this analysis suggest that Scenario 3 (Nuclear/Gas) is likely to yield the greatest net benefit of the four scenarios analysed. This conclusion is insensitive to the values assigned to key parameters. While the net benefit estimates in this report involve certain gaps and limitations, the results do provide insight into the expected relative performance of the scenarios. This insight is suitable to assist with making policy decisions concerning future electricity generation options for the province.

The results of this CBA are relevant to current initiatives by the provincial government. The government is actively pursuing a diverse range of generation technologies including refurbishing nuclear plants, increasing natural gas and renewable generation capacity, development of conservation programs and seeking contracts to import hydroelectric generation from other provinces. As new information becomes available in the future, further analysis will be able to refine the net benefits estimates associated with potential electricity generation alternatives.

ACKNOWLEDGEMENTS

This analysis has benefited from information, advice and critical review by several people. Their assistance is acknowledged and sincerely appreciated.

Takis Plagiannakos, Ontario Ministry of Energy, served as the Ministry's project manager. In addition, he provided ongoing and valuable technical comments regarding many aspects of the study.

Blair Seckington, Ontario Power Generation, provided detailed cost and emissions data for coal-fired generation facilities. As well, he provided valuable input on the gas conversion costs associated with these facilities.

Shaibu Gariba, Ontario Ministry of Energy, provided valuable assistance with the financial cost estimation methodology for the scenarios. His previous work developing similar financial cost estimates assisted with moving the analysis forward efficiently.

Bob Kozopas, Ontario Power Generation, participated in the scenario design discussions. He provided useful critical comments regarding the consistency of the assumptions surrounding each of the scenarios.

Dr. Alan Krupnick, Resources for the Future, Washington, D.C., reviewed the application in this study of his research findings on the value of a statistical life. He provided valuable advice based on his extensive experience developing similar damage estimates in other jurisdictions.

All of the above people served solely in an advisory role. The consulting team benefited from their knowledge and experience. However, the consulting team worked independently of these advisors and arrived at decisions on the most suitable methodology and data solely on their own accord. As a result, full responsibility for the accuracy and technical soundness of the analysis presented in this report rests with the consulting team.

Two consulting firms were involved in preparing this analysis.

RWDI AIR Inc. was responsible for developing the emissions profiles for each scenario and using these profiles to produce forecasts of the expected changes in ambient concentrations. The following people participated on the RWDI project team:

Wayne Boulton, Project Manager
Mike Lepage, Project Director
Ben Coulson, Senior Scientist
Tina Martin, Scientist.

DSS Management Consultants Inc. was responsible for the overall conduct of the project. The estimates of financial costs and health and environmental damages were prepared by DSS. The following people participated on the DSS project team:

Ed Hanna, Project Director
Dr. Peter Victor (Economic valuation methodology)
Eric Miller (Financial cost estimation, estimation of economic damages factors)
Steve Spencer (damage model programming)
Bruce Lourie (Mercury damages)
Rysa Hanna (Epidemiology literature research)

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LIST OF ACRONYMS AND UNITS USED

CBA - Cost benefit analysis
CD - Census division
CFG - Coal-fired generation
DSS - DSS Management Consultants Inc.
GHG - Greenhouse gasses
KW - Kilowatts
KWh - Kilowatt hours
MW - Megawatts
MWh - Megawatt hours
NO$_x$ - Nitrogen oxides
PM$_{2.5}$ - Particular matter less than 2.5 microns in aerodynamic diameter
PM$_{10}$ - Particular matter less than 10 microns in aerodynamic diameter
ppb - Parts per billion
ppm - Parts per million
OPG - Ontario Power Generation
RWDI - RWDI AIR Inc.
SO$_x$ - Sulphur oxides
TGS - Thermal generating station
TWh - Terawatt hours
μg/m^3 - Microgram/cubic meter
VOCs - Volatile organic compounds
VSL - Value of a statistical life

1 INTRODUCTION

1.1 Background

The following report prepared by DSS Management Consultants Inc. (DSS) and RWDI AIR Inc. (RWDI), documents a cost-benefit analysis (CBA) of electricity generation alternatives to replace the electricity production and generation capacity supplied by Ontario's coal-fired generation (CFG) stations. Various studies have been done in the U.S.A. examining the health and environmental damages associated with CFG facilities (Abt, 2002, Abt 2004, Wu, 2003 and Clear the Air, 2005). These studies have been reviewed from a methodological perspective and where appropriate, have been used for guidance concerning some air pollution risks and their quantification.

The Ontario government has made a public commitment to closing down the province's CFG stations by 2007. The Ministry of Energy requested that four distinct alternatives including maintaining the status quo were analysed using the best available and most reliable data and knowledge within a rigorous economic evaluation methodology.[2] As per the scope of work for this project, an independent CBA has been prepared which focuses on quantifying the health and environmental risks posed by air pollution emissions from the four generation alternatives specified.

1.2 Purpose and Scope

The purpose of this study is to produce estimates of the physical and economic damages associated with air pollution emissions from alternative means of replacing coal-fired electricity generation. In addition, estimates of the capital and variable and fixed operating costs (including fuel costs) of the alternatives were produced. Combining these measures allowed the economic net benefit of the alternatives to be estimated.

Physical and economic damage estimates were not possible for all sensitive receptors. These gaps are identified and discussed later in this report. For this reason, the net benefit estimates presented in this report need to be interpreted with care.

This study is limited to health and environmental risks associated with ground-level ozone (referred to simply as ozone or O_3 throughout the remainder of this report) and particulate matter (primarily fine particulate matter less than 2.5 microns in aerodynamic diameter denoted as $PM_{2.5}$ throughout the remainder of this report). In addition, economic damages associated with greenhouse gas (GHG) emissions were estimated.

Ontario's CFG stations are scheduled to be closed in 2007. For adequate replacement capacity to be available at that time, capital investments will need to be made beforehand. In addition, any investments made to replace CFG generation will have a useful life for a number of years thereafter. As a result, this analysis estimated health and environmental damages from 2007 to 2026. Financial costs of generation were estimated from 2005 to 2026 to cover the period of initial capital investments for replacement capacity.

Currently, Ontario has five CFG stations, namely, Lakeview, Nanticoke, Lambton, Atikokan and Thunder Bay. The Lakeview station is scheduled to be closed in the spring of 2005 and is not

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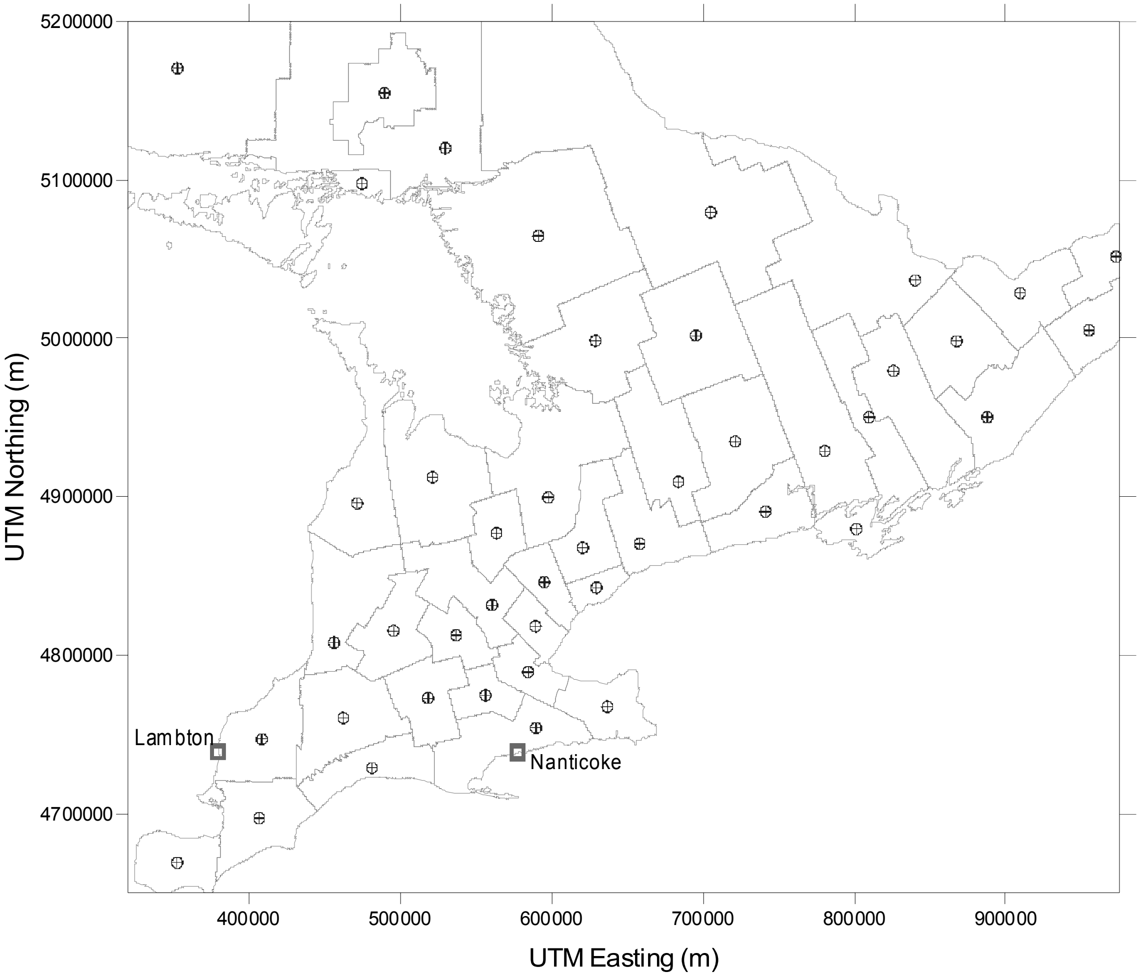
[2] The four scenarios involved various combinations of coal, gas and nuclear power generation. Clearly, other electricity generation and supply options exist (e.g., renewables, imports) but scenarios including these options have not been analysed in this study.

included in this analysis. Atikokan and Thunder Bay CFG stations contribute a small percentage of the total CFG emissions (i.e., less than 5%), account for a small amount of electricity compared to the southern Ontario stations (i.e., about 1 TWh compared to 27 TWh) and are located in an airshed with few of the sensitive receptors common in the south. For these reasons, air pollution emissions and associated health and environmental damages for these two northern stations were not included in this analysis.

Air pollution risks were estimated across all of southern Ontario. Census divisions (CD) were used as the finest level of spatial resolution (Figure 1.1). In total, 44 CDs were included. The five most northern CDs were not included but given their remote location relative to the emission sources, their omission is not expected to affect materially the overall results of this analysis.

Figure 1.1 Map Showing Location of Census Division Centroids



Note: The circles represent the census division centroids and population receptors. The Nanticoke and Lambton CFG facilities are indicated by the squares.

1.3 Report Organisation

This report documents the underlying details supporting the estimates of health and environmental damages, financial costs and net benefits of the alternatives considered. This detail is provided so that technical experts can understand and critically assess this analysis. To reduce the complexity of the main report, several technical appendices have been included that detail certain aspects of the analysis.

Chapter 2 documents the process whereby the four alternatives analysed were derived and the details associated with each were determined. The specific characteristics of these alternatives are described.

Chapter 3 describes the economic methodology used and some of the key economic parameters underlying the net benefit estimates.

Chapter 4 presents the estimates of the capital, operating and fuel costs for each alternative.

Chapter 5 outlines the data and methodology used to estimate changes in ambient air quality as a result of replacing CFG facilities. Greater technical detail is provided in Appendix A.

Chapter 6 deals with the health risks of air pollution and the economic valuation of estimated physical damages (i.e., morbidity and mortality). The estimated health damages for each alternative are presented and discussed.

Chapter 7 deals with the environmental risks of air pollution and the economic valuation of estimated physical impacts (i.e., soiling of materials, impacts on agriculture and climate change impacts). The estimated environmental health damages for each alternative are presented and discussed.

Chapter 8 discusses the aggregate costs and benefits of the scenarios.

Chapter 9 includes a discussion of limitations and recommendations for further analysis.

Chapter 10 provides a summary of the overall findings of this analysis.

2 SCENARIO DEVELOPMENT

This CBA involves comparing the costs and benefits of a range of scenarios (i.e., electricity generation alternatives) for Ontario. This section describes how the scenarios were determined and the specific characteristics and underlying assumptions associated with each.

2.1 Scenario Design Process

The four basic scenarios analysed in this report were initially conceptualised by the Ontario Ministry of Energy and were included in the original scope of work. Before the costs and benefits of each scenario could be estimated, more precise technical details needed to be determined for each scenario. These details included factors affecting emission rates and financial costs.

These details for each scenario were developed collectively through discussions among technical experts from the Ontario Ministry of Energy, Ontario Power Generation (OPG), RWDI, and DSS. The process involved resolving a number of important considerations including, the amount of CFG electricity generation that needed to be replaced, what assumptions should be made concerning other changes in the provincial and regional electricity market, how to distinguish between new replacement generation and existing commitments, etc.

These discussions resulted in a detailed set of technical parameters for every facility included in one or more of the scenarios. These parameters were used by RWDI to develop the emissions profiles used in the air quality modelling. DSS used these parameters to estimate the financial costs of constructing and operating the facilities proposed to replace Ontario's CFG facilities.

A key simplifying assumption underlying the scenarios is that the level of utilisation of the replacement facilities was determined only in terms of offsetting the generation lost when the CFG facilities are closed. No allowance was made to reflect potential external electricity market forces that might cause some or all of the facilities in one or more scenarios to be operated differently. In effect, the replacement facilities were assumed to be operated solely to produce the electricity needed to replace that produced by CFG facilities.

This assumption has likely caused some or all of the new gas generation facilities to appear to be used less than what might otherwise be the case. This under-utilisation will tend to exaggerate the emission rates per kWh produced since emissions are proportionately higher when gas turbines are regularly fired up and down. Similarly, the capital and fixed operating costs are spread over a lower total amount of generated electricity causing the total financial costs needed to produce the replacement electricity to increase. This assumption will tend to bias the analysis in favour of Scenarios 1 (Base Case) and 4 (Stringent Controls). With both of these scenarios, the existing CFG capacity is assumed to continue to be used as is the case at the present time and no new gas generation replacement capacity would need to be added to the system[3].

Closing down the province's CFG facilities will likely have far-reaching implications, not the least of which is the requirement for significant capital investments in alternate generation technology. For this reason, examining the benefits and costs over an extended timeframe is warranted. As a result, a forecast horizon of 20 years (i.e., 2007 to 2026) was used. Extending the forecast horizon would increase marginally the absolute magnitude of the estimated present value of costs and benefits but would not significantly alter the relative differences among the scenarios.

2.2 Scenario Descriptions

Following is a description of the four scenarios that have been analysed. Table 2-1 summarises the key capacity and generation features for each scenario.

2.2.1 Scenario 1 - Base Case

Scenario 1 (Base Case) represents the status quo. With this scenario, OPG's Lambton and Nanticoke CFG stations are assumed to continue operating after 2007. These facilities would need to meet their 2007 emission cap[4] (i.e., an annual maximum of 17 Gg + 33% of NO_X emitted). With the Base Case, it is assumed that with current emission cap and current equipment configurations, OPG facilities would be able to produce annually about 26.6 TWh of electricity.

This electricity production rate may in fact vary over time for a multitude of reasons (e.g., more stringent emissions regulations, unexpected changes in the provincial generation system, emissions trading and banking of credits). Assessing the effects of such variations was outside the scope of this study. The key requirement was that all scenarios were designed based on similar generation levels and in this case, the common generation level was 26.6 TWh per year.

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[3] Note that this analysis deals only with the provincial CFG facilities and the need to replace their electricity generation if they are closed down. New gas-fired generation facilities may be built in Ontario in the future to meet expanding demand irrespective of the government's decision on the CFG facilities. The effects of any such new capacity on the provincial electricity market have not been examined as part of this analysis.

[4] Ontario Regulation 397 has established emissions caps for the province's coal-fired generation facilities. These emission caps were assumed to be met in the base case and this is reflected in the electricity generation output and emission profiles for this scenario.

Table 2-1 Key Capacity and Generation Parameters

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/Gas**	**4 Stringent Controls**
Total Capacity (MW)	**6,447**	**6,447**	**6,447**	**6,447**
Total Generation (TWh)	**26.6**	**26.6**	**26.8**	**26.6**
CCGT[a] (TWh)	**0**	**26.6**	**7.6**	**0**
SCGT[b] (TWh)	**0**	**0**	**1.0**	**0**
Refurbished Nuclear (TWh)	**0**	**0**	**18.2**	**0**

a: **CCGT** = combined cycle gas turbine generation
b: **SCGT** = single cycle gas turbine generation

2.2.2 Scenario 2 - All Gas

Scenario 2 (All Gas) involved identifying potential new gas generation facilities throughout southern Ontario that would be required to come online to replace lost generation and capacity at the Lambton and Nanticoke CFG stations. These new gas generation plants are assumed all to be using combined cycle gas turbine technology and to be operated at a level adequate to replace the electricity supply provided by the CFG plants in Scenario 1 (Base Case). Air pollutant emissions were estimated for these gas generation plants based on their expected size, operating conditions and technology. Emission factors and stack parameters were determined based on information from engineering estimates and other public sources. Generation capacity and average load factors for these new gas generation facilities were developed through discussions with OPG and the Ontario Ministry of Energy. Much of the information concerning these new plants, many of which are being proposed by private operators, including their geographic locations, was obtained from the IESO website.
http://www.ieso.ca/imoweb/monthsYears/monthsAhead.asp

2.2.3 Scenario 3 - Nuclear/Gas

With Scenario 3 (Nuclear/Gas), less electricity is generated from gas than is the case with Scenario 2 (All Gas). The difference in electricity generation comes from refurbished nuclear stations. Given the lower overall generation with gas, some single-cycle gas turbines were included and were designed to be used for meeting a portion of the peak demand. Using the more expensive combined cycle technology for all of the gas-generated electricity in this scenario would not be reasonable given the much lower load factors. Most of the base load demand would be met through bringing existing, non-operating nuclear units back on line. More specifically, three additional nuclear units were assumed to be brought back on line at Pickering A (Units 1, 2 and 3). As well, Units 1 and 2 at the Bruce nuclear plant were assumed to be brought on line by 2007.

2.2.4 Scenario 4 - Stringent Controls

Scenario 4 (Stringent Controls) assumes that significant additional emission control retrofits were installed at all of the existing CFG plants. Specifically, all the units were assumed to have installed by 2007, Selective Catalytic Reduction (SCRs) to control NOx emissions, Flue Gas Desulphurization (FGD) scrubbers to control SO_2 emissions and enhancements to existing Electrostatic Precipitators (EP) to better control particulates. Although these additional emission controls would reduce significantly sulphur oxides (SOx), nitrogen oxides (NOx) and fine particulate emissions, they would not significantly affect GHG emissions. With the installation of these emission controls, the CFG facilities were assumed to achieve best available control technology (BACT) emission rates. These emission control technologies would not significantly affect the overall generation capacity of the facilities so no replacement capacity was assumed to be required.

3 Economic Valuation

This study involves estimates of the physical and economic damages associated with the four scenarios described in Section 2. Converting physical damages to economic measures involves applying certain economic rules and conventions. This section briefly reviews some of the key economic principles on which this study is based.

3.1 Avoided Damages

This CBA uses an avoided damages methodology. This methodology is commonly used in public policy analyses involving potential improvements in environmental quality (US EPA, 2003, CCME, 2001; ExternE, 2003; Holland and Watkiss, nd.). The benefit of environmental improvements is the reduced risk of future damages (i.e., avoided damages). These avoided damages are measured relative to doing nothing (i.e., maintaining the status quo).

The avoided damages methodology requires estimates of expected damages under at least two conditions, namely, the status quo and some change in policy affecting environmental quality. In this study, Scenario 1 (Base Case) serves as the reference case against which reductions in damages are estimated. Similarly, the increase in costs for each scenario was compared to the costs of continuing with the Base Case. Summing the financial costs and health and environmental damages for each scenario provides an estimate of the total cost of generation. Subtracting the total cost of generation for a given scenario from the total costs of generation for the Base Case yields an estimate of net benefit (or net cost) for that scenario.

3.2 Social Discount Rate

When forecasts of costs and benefits are made over an extended period of time, the economic methodology needs to be refined. More specifically, to arrive at a comparable assessment of the net benefits of the scenarios, allowance must be made for the timing of costs and benefits. A social discount rate was used to estimate the present value of avoided damages and financing costs associated with capital investments, operating and maintenance costs and fuel costs.

An extensive literature exists discussing the theory, principles and derivation of an appropriate discount rate to use in various types of studies and in particular, environmental policy analyses (for a recent survey, see Sumaila and Walters, 2005). The streams of financial costs and health and environmental benefits over time differ among the scenarios. Discounting allows differing streams of costs and benefits to be compared directly. The discount rate can significantly influence net benefit estimates. Sensitivity analysis is commonly used to evaluate the degree of influence of the discount rate on the final results. Where the final results are highly sensitive to the discount rate used, greater care is required in choosing the most appropriate value. The social discount rate was one of the sensitivity parameters analysed in this study. The results of this sensitivity analysis are presented in Section 8.4.

A social discount rate of 5% was selected in consultation with the Ontario Ministry of Energy. This rate was used to derive the central (i.e., best estimate) values in this analysis. In the sensitivity analysis, a range from 3% to 10% was examined. The central value and sensitivity range is consistent with the Ontario government's use of a discount rate for analysing investments in long-term projects (Spiro, 2004). The social discount rate is applied to the estimated streams of health and environmental damages in addition to financial costs. As well, the social discount rate is used to discount the physical supply of electricity as part of the levelised costs estimation procedure (see Section 3.33 for further explanation).

3.3 Economic Metrics

Three metrics are used to present the results of this analysis. A brief description of each follows.

Total present value represents the cumulative discounted value of a stream of benefits or costs over a given period of time. Standard economic methods were used to discount future streams of costs and damages to arrive at a present value measure.

Annualised value represents the average annual value of a stream of benefits or costs that is equal to the total present value spread evenly over the time period. In concept, the annualised value is the annual payment that would be required if a mortgage equal to the total present value was paid back in equal annual instalments over the time period of the analysis.

Levelised value is the total present value divided by the discounted (using the social discount rate) total generation (MWh). The levelised value expressed in $/MWh, provides a convenient means to express the electricity costs that are attributable to the financial costs of generation and health and environmental damages.

All of the economic values included in the report are expressed in constant 2004 Canadian dollars. Where economic measures are expressed based on other base years, a 2% annual inflation factor was used to adjust the measures to 2004 equivalent dollars.

4 CAPITAL, OPERATING, AND FUEL COSTS

This section outlines the methodology used to estimate the financial costs of the four scenarios. The resulting cost estimates are discussed at the end of this section.

4.1 Methodology

All of the scenarios involved certain financial costs, although these costs differed significantly from one scenario to another. The costs estimates derived in this analysis capture the capital, variable and fixed operating and fuel costs for each scenario. These costs were estimated over the entire forecast horizon (i.e., 2005[5] to 2026).

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[5] Note, health and environmental damages are based on a forecast horizon of 2007 to 2026. With the financial costs, 2005 was the start year to provide a two-year window for construction of new/refurbished facilities.

The capital, operating, and fuel costs for each scenario were developed in consultation with the Ministry of Energy and Ontario Power Generation. These costs were developed on a per-generation station and per-unit basis. Conversion or control costs differed significantly among stations and units, in the case of the large CFG facilities. This section summarizes the methods used to estimate generation costs associated with each scenario.

4.1.1 Capital Costs

Capital costs involve the construction of new generation capacity or the refurbishment of existing generation facilities. Routine maintenance of existing generation facilities was included in fixed operating costs.

Table 4-1 provides the financial factors used to estimate of the capital, operating and maintenance costs for Scenario 1. Scenario 1 (Base Case) relies on the existing equipment and buildings at the CFG facilities. Following normal practice, no allowance for the capital value of the existing facilities was included in the analysis because these funds have already been expended and they cannot be altered by any future decision. Nonetheless, all of the CFG facilities were assumed to require some additional refurbishment over the time period considered in this analysis. Refurbishment of the Lambton and Nanticoke CFG facilities was assumed to occur, two units per year, from 2008 to 2013. Thunder Bay was assumed to be refurbished in 2011 and Atikokan in 2012.

Table 4-1 Cost Assumptions for Scenario 1 (Base Case)

Facility	Unit	Refurbishment ($Million/Unit)	Fixed Operating & Maintenance ($/kW)	Variable Operating & Maintenance ($/MWh)
Nanticoke	Units 7&8	**$47**	**$31**	**$2.07**
	Units 1-6	**$47**	**$33**	**$2.20**
Lambton	Units 3&4	**$47**	**$34**	**$2.40**
	Units 1&2	**$47**	**$38**	**$2.40**
Thunder Bay	Units 1&2	**$28**	**$73**	**$5.00**
Atikokan	Unit 1	**$22**	**$73**	**$5.00**

New generation capacity was required for Scenarios 2 (All Gas) and 3 (Nuclear/Gas). Table 4-2 provides the financial factors used to estimate the capital, operating and maintenance costs for new gas facilities. With these scenarios, some of the existing CFG facilities would need to be replaced with gas; as well, new gas generation capacity was assumed to be added at new locations. With Scenario 3 (Nuclear/Gas), capital investments also required bringing existing mothballed nuclear capacity online (Table 4-3). Less capital cost was incurred for new gas generation capacity with Scenario 3 (Nuclear/Gas) because some of the capacity and most of the generation came from refurbishing existing nuclear facilities. In the case of the CFG sites, a capital allowance was included in the Scenario 2 and 3 estimates for the cost of linking the facilities to existing gas pipelines and associated CCGT/SCGT replacement costs; however, the pipeline costs for Scenario 3 (Nuclear/Gas) were somewhat less due to the reduced size of the pipeline required.

Table 4-2 Cost Assumptions for New and Replacement Gas Facilities

Facility	**Size of Unit**	**Capital** ($/kW)	**Pipeline** ($Million)	**Fixed Operating & Maintenance** ($/kW)	**Variable Operating & Maintenance** ($/MWh)
Replacement CCGT at Nanticoke	Small	**$1,000**	**$200**	**$17**	**$3.40**
	Large	**$800**	**$300**	**$13**	**$3.40**
Replacement CCGT at Lambton	Small	**$1,000**	**$10**	**$17**	**$3.40**
	Large	**$800**	**$10**	**$13**	**$3.40**
New CCGT	Small	**$1,000**	**$0**	**$17**	**$3.40**
	Medium	**$900**	**$0**	**$15**	**$3.40**
	Large	**$800**	**$0**	**$13**	**$3.40**
New SCGT	Medium	**$600**	**$0**	**$17**	**$3.40**

Notes: **CCGT**=Combined Cycle Gas Turbine; **SCGT**=Single Cycle Gas Turbine;
Small gas facilities=100-250MW; **Medium gas facilities**=250-600MW;
Large gas facilities=600MW and greater.

Table 4-3 Cost Assumptions for Refurbishing Nuclear Facilities

Facility	**Unit**	**Capital** ($/KW)	**Fixed Operating & Maintenance** ($/KW)	**Variable Operating & Maintenance** ($/MWh)
Refurbished Nuclear	Pickering	**$1400**	**$7.80**	**$18.30**
	Bruce	**$1300**	**$19.48**	**$7.00**

In the case of Scenario 4 (Stringent Controls), capital costs included both the cost of the new emission control technologies plus the refurbishing of the existing CFG facilities (Table 4-4). The emission control devices were added such that the best available control technology for emissions of conventional pollutants (but not including GHG emissions) was installed at these facilities. The refurbishment of the CFG facilities would have occurred at a somewhat later time according to the schedule described for Scenario 1 (Base Case). However operationally, the refurbishment would likely be scheduled to coincide with the installation of the additional emission control devices. Scenario 4 also relied on the existing capital stock of equipment and buildings at the CFG facilities. No allowance for the capital value of these facilities was included in the analysis.

The expected useful life of the capital investments in all scenarios did not coincide with the forecast time horizon. Where the useful life of a facility or equipment was shorter than the end of the forecast horizon, a financial allowance was made for refurbishment or replacement to occur at the end of its expected useful life. In so doing, the useful life of all facilities and equipment was extended to be equal to or greater than the end of the forecast horizon. To avoid having to account separately for the value of any residual useful life of capital stocks at the end of the forecast period, the following adjustment was made.

Table 4-4 Cost Assumptions for Scenario 4 (Stringent Controls)

Facility	Unit/Control	Capital ($Million/Unit)	Fixed Operating & Maintenance ($/KW)	Variable Operating & Maintenance ($/MWh)
Nanticoke	Units 7&8[a] Scrubbers EPs[b]	**$287**	**$31.86**	**$2.78**
	Units 1-6 SCRs Scrubbers EPs	**$334**	**$35.86**	**$4.04**
Lambton	Units 3&4[c] EPs	**$75**	**$34.00**	**$2.40**
	Units 1&2 SCRs Scrubbers EPs	**$334**	**$40.86**	**$4.24**
Thunder Bay	Units 1&2 SCR Scrubbers EPs	**$168**	**$76.11**	**$6.99**
Atikokan	Unit 1 SCR Scrubbers EPs	**$206**	**$76.29**	**$7.11**

a: Units have already installed Selective Catalytic Reduction (SCR) technology
b: EPs = Electrostatic Precipitators
c: Units have already installed Scrubbers and Selective Catalytic Reduction technologies

All capital costs (e.g., for new equipment) were first amortised over the expected useful life of the investment. The present value of the annual amortised payments for the forecast horizon (i.e., 2005 to 2026) was then calculated and included in the present value of the alternative under consideration. This approach avoided the problem of having to account separately for any residual value of the investment at the end of the forecast period.

4.1.2 Operating and Maintenance Costs

Fixed operating and maintenance costs were estimated as a function of electricity generation capacity (MW). Variable operating and maintenance costs were estimated as a function of generation (MWh). Generation was assumed to begin at the start in 2007 following two years of construction. Operating and maintenance costs were assumed to begin at this time.

Operating and maintenance costs were incurred annually. This stream of annual costs was discounted using the social discount rate to estimate a corresponding present value.

4.1.3 Fuel Costs

Fuel costs were estimated separately from operating costs. The fuels used varied considerably among the scenarios and among the different generation technologies.

Coal Prices

Coal prices were estimated based on discussions with OPG and the Ontario Ministry of Energy. The coal prices used in this analysis are presented in Table 4-5. Coal fuel costs differed between Scenarios 1 and 4 due to different blends of coal and increased efficiencies realised when the units were refurbished before new emissions control technologies were installed. The fuel costs were estimated by forecasting the impact of refurbishments on the heat rate and then on a per-unit basis of electricity produced. Refurbishment increased the fuel efficiency of all units. With the Thunder Bay and Atikokan facilities, the addition of control technologies offset the fuel efficiencies of refurbishment, resulting in higher fuelling costs relative to the base case. The fuel costs for these two northern facilities were assumed to remain constant over time.

Table 4-5 Coal Prices

	Coal Type ($/MMBTU)			
	PRB[a]	**USLS**[b]	**USHS**[c]	**Lignite**
Nanticoke	**$2.03**	**$2.98**	**$2.27**	**-**
Lambton	**$2.03**	**$2.98**	**$2.27**	**-**
Thunder Bay	**$1.60**	**-**	**-**	**$1.60**
Atikokan	**$1.80**	**-**	**-**	**$1.56**

a: **PRB** = Powder River Basin
b: **USLS** = US Low Sulfur Bituminous
c: **USHS** = US High Sulfur Bituminous

Refurbishment was included in the capital costs of Scenario 1 (Base Case). Some improvement in fuel efficiency may be realised from refurbishment but no allowance of this effect was included in the scenario parameters. As a result, coal fuel costs were constant over the forecast horizon for Scenario 1.

Nuclear Fuel Costs

Nuclear fuel costs were estimated based on discussions with the Ontario Ministry of Energy. Nuclear fuel costs were minor relative to the costs of other fuels. At $1.80/MWh for both nuclear facilities, nuclear fuel amounted to 1 to 2% of the cost of coal and gas on a per MWh basis. Accordingly, no range of nuclear fuel prices was analysed.

Gas Fuel Costs

The price of gas is influenced by several factors. More specifically, the fuel costs for gas generation were estimated as a function of heat rates, generation capacity, and the proportion representing long-term assured demand. A range of gas prices was tested in the sensitivity analysis. Gas facilities supplying base load electricity operate at lower heat rates and produce more electricity per unit of fuel consumed. The base load proportion was estimated on the basis of the average capacity factor for each gas facility. Table 4-6 provides the base and peak heat rate assumptions used for each generic type of gas facility. A weighted average heat rate was estimated for each facility type. The weighted average was calculated as the proportion of base load multiplied by the base load heat rate, plus the proportion of peak load multiplied by the peak heat rate.

Table 4-6 Heat Rate Assumptions for Gas Generation Facilities

Facility	Size of Unit	Base Load Heat Rate (BTU/KWh)	Peaking Load Heat Rate (BTU/KWh)
CCGT	Small	**7,300**	**7,700**
	Medium	**7,000**	**7,400**
	Large	**7,000**	**7,400**
SCGT	Medium	**10,500**	**11,500**

Notes: **CCGT**=Combined Cycle Gas Turbine; **SCGT**=Single Cycle Gas Turbine;
Small gas facilities=100-250MW; **Medium gas facilities**=250-600MW;
Large gas facilities=600MW and greater.

Table 4-7 provides the gas price forecasts used to derive gas fuel costs. A range of Henry Hub prices was developed from various gas market forecasts provided by the Ontario Ministry of Energy. Shipping and distribution costs were added to arrive at an expected Ontario delivered price. The trend in real price of each fuel over time was included in the fuel cost estimates. Forecasts of fuel prices were approximated by linear growth rates and applied over the forecast horizon. The impact of variations in price trends was tested as part of the sensitivity analysis

Table 4-7 Gas Price Forecasts

Narrative	Load Factor		Annual Increase (%)
	65%	90%	
Low	**$6.00**[a]	**$5.50**	**0**
Low and rising	**$6.00**	**$5.50**	**+ 1.0**
Medium and rising	**$6.50**	**$6.00**	**+ 0.7**
High and rising	**$9.00**	**$8.50**	**+ 2.0**

a: All values are average delivered gas price expressed as 2004$ CDN/MillionBTU

Prices vary according to the proportion of the total fuel demand that is assured over the long term (i.e., used for base load power generation). Prices for two base load factors (i.e., 65% and 90%) were provided. A linear relationship between load factor and price change was estimated and was used to estimate prices for the load factors associated with the gas generation facilities included in Scenarios 2 and 3. The "Medium and rising" forecast was used as the central value for the financial cost estimates. The "Low" and "High and rising" forecasts were included in the sensitivity analysis.

The price increase proportion for the “High and rising” variation is considerably higher than most market forecasts. Adding this annual price increase to initial prices that are already at the high end ensured that a comprehensive range of future gas fuel prices was captured.

4.2 Financial Costs of Scenarios

Table 4-8 provides a breakdown of the estimated financial costs for each of the four scenarios in present value terms over the analysis time horizon (2005-2026). With Scenario 1 (Base Case), the only major capital expense was refurbishment of the existing CFG facilities. Accordingly, this scenario involved the least overall financial cost. Scenario 2 (All Gas) was the most expensive with about two thirds of the cost being associated with fuel. The other two scenarios involved intermediate levels of financial costs.

These costs are based on the central values for each of the costs parameters discussed and represent the best estimate of the likely financial costs of the alternatives.

Table 4-9 presents these total costs using the three economic metrics discussed in Section 3.3. The cost of Scenario 2 (All Gas) was more than double the cost of Scenario 1 (Base Case) mainly due to higher cost of natural gas. Scenario 4 (Stringent Controls) had lower financial costs than both Scenario 2 (All Gas) and Scenario 3 (Nuclear/Gas). The direct financial costs of the four scenarios varied from a low with Scenario 1 (Base Case) of $37/MWh to a high of $78/MWh for Scenario 2 (All Gas).

Table 4-8 Estimated Capital, Operating and Fuel Costs

	Scenario			
	1 Base Case	2 All Gas	3 Nuclear/ Gas	4 Stringent Controls
Capital	**$0.5**[a]	**$5.3**	**$7.0**	**$5.0**
Fixed Operating	**$3.1**	**$1.2**	**$1.3**	**$3.3**
Variable Operating	**$0.7**	**$1.0**	**$3.0**	**$1.2**
Fuel	**$6.8**	**$16.0**	**$5.9**	**$6.0**
Total[b]	**$11.1**	**$23.5**	**$17.3**	**$15.5**

a: All values are expressed as 2004$ Billions of present value costs incurred from 2005-2026.
b: Column totals may not add up exactly due to rounding.

Table 4-9 Total Present Value, Annualised and Levelised Financial Costs

	Scenario			
	1 Base Case	2 All Gas	3 Nuclear/ Gas	4 Stringent Controls
Total PV (2004$ billions)	**$11.1**	**$ 23.5**	**$ 17.3**	**$ 15.5**
Annualised (2004$ millions)	**$ 985**	**$ 2,076**	**$ 1,529**	**$ 1,367**
Levelised (2004$/MWh)	**$ 37**	**$ 78**	**$ 57**	**$ 51**

5 AIR QUALITY MODELLING

Estimating the health and environmental damages of thermal electricity generation requires determining the impact of emitted air pollutants on the quality of air where sensitive receptors are located, be those receptors people or environmental elements. Connecting emissions to ambient air quality is complicated by factors such as regional air movement patterns, background pollution levels, atmospheric chemical and physical processes, and short-term changes in weather. Computer models have been developed to produce estimates of this sort. These models are routinely used in many jurisdictions in North America and elsewhere, for environmental policy analyses similar to this one (US EPA, 2003).

5.1 Methodology

The air pollution modelling methodology used in this analysis provides an intermediate level of precision. Emission characteristics and atmospheric transport and chemical transformation characteristics were included but certain simplifications were necessary to satisfy the practical constraints of available information, time and budget. Following is a description of the methodology used to estimate ambient air quality effects for the four scenarios. More technical details of the air quality modelling are provided in Appendix A.

5.1.1 Emissions Profiles

The first step in modelling ambient air quality impacts of air pollutant emissions is to determine the characteristics of the pollution source and the pollutants that are being emitted. Emissions profiles were required not only for the existing CFG stations but also for all replacement facilities.

Forecasts of annual emissions of particulate matter (less than or equal to 10 microns, PM_{10}[6]), sulphur dioxide (SO_2) and oxides of nitrogen (NO_X) for each scenario were developed in consultation with OPG and the Ontario Ministry of Energy. The emission information was supplemented with information from manufacturers' specifications and operating reports.

The size and locations of replacement facilities was based on available information regarding known proposals for new gas-fired generation stations throughout Ontario. The emission characteristics of these facilities were based on assumed technology, size and loading rate. Table A-1 to Table A-4 provide details for all of the emissions profiles used in this study. The total annual emissions associated with each of the scenarios are shown in Table 5-1.

5.1.2 Meteorological Modelling

Air pollution is carried in the atmosphere by the movement of weather systems. These weather systems play a major role in dispersion, chemical transformation and deposition relationships. Accordingly, deriving estimates of the effects of pollution emissions on ambient air quality requires modelling the behaviour of weather systems.

The meteorological modelling in this analysis was performed using CALMET (Scire *et al.*, 2000), which, in combination with surface and upper air meteorological data and geophysical parameters, generates 3-dimensional meteorological fields. A relatively coarse resolution of 20 km spacing was used for southern Ontario.

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[6] PM_{10} and $PM_{2.5.}$ (particulate matter less than or equal to 10 and 2.5 microns, respectively) are both used to estimate health damages. Virtually all of the PM estimated in these air quality forecasts is $PM_{2.5}$. Furthermore, measures of PM_{10} include $PM_{2.5}$. As a result, these measures are used interchangeably in this analysis.

Table 5-1 Annual Emissions Associated with Each Scenario

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
GHG (MT CO_2 eq)	**25**	**10**	**3.4**	**25**
SO_x (Kt)	**93**	**0.06**	**0.02**	**19**
NO_x (Kt)	**24**	**2.3**	**1.2**	**8**
PM_{10} (Kt)	**4.3**	**0.89**	**0.33**	**0.27**
Hg (Kg)	**433**	**0**	**0**	**108**

The meteorological modelling used surface and upper air meteorological data from 1999 comprising a total of 8,760 hours of observational data. The year 1999 was selected as data for that year were already available in a suitable format. As well, the data for 1999 provided a good cross-section of typical large-scale weather patterns throughout the study area. The study could be enhanced by using more than a single year of meteorological data, but using just the 1999 data represented a reasonable approach consistent with the practical constraints of computer run time, file management, and the project schedule and budget.

5.1.3 Air Pollutant Dispersion and Transformation Modelling

The impacts of emissions from power plants on air quality were modelled using CALPUFF with meteorological inputs from CALMET. CALPUFF is a multi-layer, multi-species, non-steady-state puff dispersion model, which can simulate the effects of time and space varying meteorological conditions on pollutant transport, transformation, and deposition (Scire *et al.*, 1999). The CALPUFF model requires the user to define the location where pollutant concentrations are to be calculated (receptors). The CALPUFF model spatial domain coincided exactly with that used in CALMET. Forty-four census division receptors were used.

Atmospheric particulate matter (including PM_{10}) can be emitted directly by emission sources or can be formed in the atmosphere by chemical reactions involving precursor emissions. Specifically, emissions of SO_2, NO_X and volatile organic compounds (VOCs) can lead to the secondary formation of PM. As discussed in greater detail in Appendix A, PM chemical transformation was modelled in CALPUFF to account for the conversion of SO_2 to sulphate (SO_4), and NO_X to nitrate (NO_3^-). Estimates of secondarily derived PM_{10} (i.e., particle nitrate and particle sulphate) were summed with primary PM_{10} concentrations to arrive at total PM_{10} concentrations at each receptor.

Relationships between NO_X and VOCs and how they relate to ozone (O_3) in different parts of southern Ontario were developed from ambient monitoring data. A first-order approximation of O_3 formation was derived as a function of NO_X and VOCs. This derived relationship was used to estimate the contribution of power plant emissions to seasonally averaged peak 8-hour O_3 concentrations. The methodology used for these estimates is detailed in Appendix A.

5.2 Estimated Changes in Ambient Air Quality

The estimated change in ambient air quality varies throughout the province according to location relative to the emission sources and the scenario being considered. The greatest effect generally occurs immediately downwind and declines as the distance from a source increases; however, when multiple sources are involved, the relationships become increasing complicated.

Table 5-2 provides representative examples of the estimated percentage reductions in air quality for Scenarios 2, 3, and 4. The values in this table are expressed as the difference in pollutant concentration relative to Scenario 1 (Base Case). For example, a reduction of 50% implies that the emissions associated with the given scenario will contribute 50% less pollution than was contributed with Scenario 1. These percent reductions are not estimates of the percent reduction in the total ambient concentration of each pollutant, only the percent reduction in the pollution concentration attributable to CFG emissions. The estimated absolute contribution to ambient air pollution of emissions from each scenario for PM_{10} and O_3 are presented in Table A-6.

Table 5-2 Percent Reduction in Air Pollution Impacts for Representative Locations

	Scenario 2 All Gas		**Scenario 3 (Nuclear/Gas) Nuclear/Gas**		**Scenario 4 Stringent Controls**	
	O_3 (ppb)	**$PM_{2.5}$ (µg/m3)**	**O_3 (ppb)**	**$PM_{2.5}$ (µg/m3)**	**O_3 (ppb)**	**$PM_{2.5}$ (µg/m3)**
Toronto	**- 45%** [a]	**96%**	**7%**	**98%**	**51%**	**73%**
Haldimand-Norfolk	**93%**	**99%**	**96%**	**99%**	**48%**	**69%**
Peterborough	**66%**	**73%**	**37%**	**97%**	**77%**	**98%**

a: All values are expressed as the percent change in concentration relative to the average concentration contributed by emissions associated with Scenario 1 (Base Case). The negative value for Toronto with Scenario 2 indicates an increase in ozone concentration is expected.

The model results indicate that for Scenario 1 (Base Case), the highest O_3 concentrations resulting from CFG emissions occur in the Regional Municipality of Haldimand-Norfolk. The estimated peak 8-hour daytime average concentration during the summer months attributed to this scenario is about 2 ppb[7] and the attributable maximum 24-hour PM_{10} concentration is about 4 $\mu g/m^3$.

Overall, closing down the CFG facilities is forecast to improve air quality in most parts of southern Ontario. .In general, the other three scenarios result in quite large percent reductions in the ambient pollutant concentrations linked to emissions produced with Scenario 1 (Base Case). However, these improvements are small compared to the overall ambient concentrations of these pollutants. The ambient concentrations of these pollutants are influenced by various sources including transboundary air pollution and vehicle emissions.

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[7] All concentrations of pollutants reflect only that portion attributable to electricity generation emissions. Actual ambient concentrations will differ significantly due to the contribution of pollutants from many other sources, including transboundary air pollution.

Small increases in O_3 concentrations are forecast with Scenario 2 (All Gas) in the Toronto area. In other words, closing the CFG facilities is estimated to increase ozone concentrations in Toronto, albeit, quite slightly, if all of the replacement electricity was generated by gas turbines. This outcome is due to increases in NO_x emissions from new gas generation facilities assumed to be in close proximity to the city.

6 HEALTH DAMAGES

The risks of adverse health effects from air pollution have become increasingly well documented over the last several decades (HEI, 2003; CEPA, 2004; US EPA, 2005). Effects have been observed in countries around the world using various epidemiological methods (e.g., time series, cohort and cross-sectional studies). In addition, physiological and clinical evidence is available that demonstrates human reactions to air pollutants (US EPA, 2005). Governments around the world are imposing increasingly stringent air quality standards to reduce the health risks associated with these pollutants (APHEIS, 2004). These risks include a wide range of health outcomes from minor illnesses to premature death. These risks are largely tied to exposure to ozone and PM. However, there is evidence suggesting that other air pollutants may be causing additional health damages (e.g., NO_2, CO, SO_2).

The level of risk depends on a number of factors, including types of air pollutants present and their concentrations and the demographics and health characteristics of the exposed population. The methodology for estimating the risk of health damages associated with air pollution has become quite standard in many jurisdictions. Health damage estimates have played a major role in public policy decisions including new air quality regulations (e.g., CCME, 2001; WHO, 2003; US EPA, 2004; ExternE, 2003). This section outlines the health damages methodology used in this study and the estimated health damages associated with each of the four scenarios.

6.1 Methodology

The basic methodology used in this study is similar to that used elsewhere to estimate health damages from air pollution. The standard methodology involves the following key parameters:

- Ambient air pollution levels to which the population at risk is likely exposed
- The demographics of the exposed population, most importantly age
- The baseline (i.e., in the absence of elevated air pollution) incidence rates for key illnesses
- Relative risks for specific health outcomes for sensitive segments of the population exposed to air pollution
- Economic cost factors (e.g., cost of treatment, pain and suffering) for each type of illness

The following sections outline the sources relied on to compile the information required to prepare health damage estimates.

6.1.1 Population Data

The 2001 census population data for Ontario were used in this analysis. The 2001 census data include detailed breakdowns by age and gender at a CD level of spatial resolution. These data were aggregated into three age groups that correspond to sensitivity to exposure to air pollution, namely, less than 19, 19 to 65 and greater than 65. The 2001 population figures were adjusted to 2003 values using the population forecasts published by Statistics Canada along with the census data.

6.1.2 Air Quality Data

The air quality forecasts described in Chapter 5 were used to estimate exposure to air pollution within each CD. The scientific evidence demonstrating that the $PM_{2.5}$ fraction accounts for many health damages has increased substantially over the last five years (Abt, 2004, CCME, 2003). Accordingly, health damages were forecast largely based on $PM_{2.5}$ concentrations. While the CALPUFF results are reported as PM_{10} essentially all of these particles fall in the $PM_{2.5}$ size range (see Section 5.1.1). As a result, a one-to-one correspondence was used between forecast PM_{10} concentrations and the related $PM_{2.5}$ concentrations.

The CALPUFF results represent the incremental contribution of electricity generation emissions to ambient air pollution concentrations. Accordingly, no adjustments needed to be made to account for natural background concentrations. All of the health damages forecast using the CALPUFF results are attributable to air pollution associated with emissions from electricity generation.

Mercury is a significant pollutant emitted by CFG facilities (see Section B.5). However, the environmental dynamics of mercury and related human exposure levels are much more complicated to forecast than is the case with ozone and PM (see Section B.7). For this reason, mercury was addressed in a much more qualitative manner. Mercury impacts are not included in the quantitative physical and economic impact estimates on which this CBA relies.

A range of other air pollutants associated with thermal electricity generation are suspected of being directly associated with adverse health outcomes (e.g., NO_x, SO_2, carbon monoxide). The scientific evidence describing the exposure risks for these other pollutants is not as strong as it is for PM and ozone. Accordingly, the quantitative estimates of health impacts in this analysis are limited to those associated with PM and ozone.

6.1.3 Base Incidence Rates

Health risks of air pollution are expressed relative to the normal or baseline incidence rates of certain health outcomes in the population at risk. For example, a 2% increase in risk of being admitted to hospital due to an increase in air pollution means a 2% increase is expected in the base rate of hospital admissions typical for the exposed population.

Base incidence rates for all of the health outcomes were obtained from current health statistics available for Ontario (CIHI, 2002). The only exception is the base incidence rates for minor illnesses.

Standardised province-wide statistics for minor illnesses are not routinely collected and reported through a central database. As a result, considerable uncertainty exists as to the base incidence rates for minor illnesses in any given population. For the purposes of this study, the base incidence rates for minor illnesses estimated by Ostro and Rothschild (1989) as reported by Abt Associates (2003) were used.

6.1.4 Health Risk Factors

Four types of health impacts of air pollution were assessed as part of this analysis, namely, premature mortality, hospital admissions, emergency room visits and minor illnesses[8]. Following is a summary of the risk factors for each of these health outcomes on which this analysis is based.

Premature Mortality

Premature mortality risk factors are estimated using two fundamentally different epidemiological methods. The most commonly employed method is referred to as time series studies. These studies estimated the risk of short-term premature mortality immediately following (i.e., within several days) exposure to air pollution. This health effect of air pollution has been the most extensively studied. An exhaustive re-analysis of the major scientific studies of the short-term risk of premature mortality was undertaken by the Health Effects Institute (HEI, 2003). The results of this re-analysis were used as the basis for the time series premature mortality risk factors in this study.

An alternate methodology to estimate premature mortality risks relies on following a cohort of individuals over an extended number of years and assessing their health relative to their long-term exposure to air pollution (Dockery et al, 1993). These cohort studies provide risk factors for long-term exposure to air pollution. The logistics, costs and time required to undertake cohort studies are much greater than those required for time-series studies since the health of a large group of people must be carefully tracked over many years. For this reason, the number of cohort studies available in the scientific literature is more limited (Dockery, 1993, Pope et al, 1995). However, considerable effort has been expended to confirm and refine the risk factors derived from these studies (Krewski et al, 2000; Pope et al, 2002). As a result, these estimates have been sufficiently validated to be used for policy analysis (US EPA, 2005).

The cohort-derived premature mortality risk factors are more appropriate to use in a CBA like this one. Time-series estimates of the increased risk of premature mortality capture only the short-term acute effects of air pollution exposure. On the other hand, cohort-based estimates capture the risk of long-term effects and arguably, some or all of the acute effects as well. In other words, cohort-based risk factors are more inclusive of the expected health risks associated with air pollution exposure and thus provide a more accurate estimate of the expected damages. For these reasons, the health damages estimated in this study using cohort-based risk factors should be relied on for making public policy decisions.

Nonetheless, estimates of the number of premature deaths associated with short-term exposure (i.e., based on time-series risk factors) are also presented for comparison purposes. In general, the cohort risk factors are about seven times[9] greater than the comparable risk factors based on time-series studies.

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[8] One major category of health impact is not included in this analysis, namely, doctor's office visits. Few epidemiological studies are available which have estimated the relative risks of air pollution exposure for increases in doctor's office visits. For this reason, this category of health outcome is not included in this analysis. Given that exposure to air pollution does cause increases in the other four types of health outcomes, certainly, increases in doctor's office visits is likely as well. Excluding these effects of air pollution underestimates the health impacts of air pollution.

[9] The values in Table 6-5 are rounded. As a result, the ratios between acute and total premature deaths varies somewhat among the scenarios and is not exactly equal to seven.

Hospital Admissions

The hospital admission risk factors were based on the results of the HEI re-analysis (HEI, 2003). The results of Burnett et al (2003) in particular were used to estimate the hospital admission risk factors. These reported risks correspond well with others included in the HEI re-analysis.

Emergency Room Visits

The emergency room visit risk factors were based on the latest and most applicable scientific studies. Specifically, research results from work by Atkinson et al (1999), Stieb et al (1996), and Tolbert et al (2000) were the primary sources for the revised emergency room visit risk factors.

Minor Illnesses

The epidemiological literature on the risk of minor illnesses from exposure to air pollution is quite sparse relative to other more severe health outcomes. Unlike deaths, hospital admissions and emergency room visits, no qualified health practitioners are routinely diagnosing and submitting reports on these cases. Likewise, no centralised reporting system is available that can be used for epidemiological analyses. For these reasons, estimates of minor illness risks are less reliable than those for more severe illnesses.

These challenges result in two sources of uncertainty in estimating minor illnesses associated with air pollution exposure. First, the estimated risk factors are less reliable with wide uncertainty ranges. Second, the base incidence rates of various types of minor illnesses must be estimated and are not based on reliable records from central institutional database.

This study relied on the minor illness risk factors developed by Vedal et al (1998). For the purposes of this study, the base incidence rates for minor illnesses were estimated based on rates derived by Ostro and Rothschild (1989) as reported by Abt Associates (2003).

6.1.5 Economic Damage Coefficients

The estimated physical health damages are converted to economic values by calculating the economic costs associated with each type of health outcome. These economic costs included the value of avoiding premature death, pain and suffering, cost of treatment and lost productivity/time. Following is a discussion of the economic damage factors used in this analysis.

Value of a Statistical Life (Value of Reducing the Risk of Premature Death)

The risk of premature mortality from exposure to air pollution is commonly reported as the number of premature deaths attributable to air pollution. This figure is often the source of much confusion. Expressing the results in terms of expected numbers of premature deaths is a simple way to communicate the change in risk of premature mortality that occurs when members of a population are exposed to a change in air quality. More accurately, what is being forecast is the average change in risk that each individual in the exposed population experiences with a change in air quality. Multiplying this change in risk by the number of people exposed leads to an estimate of the number of premature deaths attributable to a given change in air quality.

In actual fact, it is impossible to identify which specific deaths that occur over a given period of time are actually attributable to air pollution. Air pollution is a contributory factor in a multitude of deaths and is almost never the overriding or irrefutable cause of death. This in no way implies that air pollution is not causing premature mortality among a great number of individuals. Instead, reporting the change in risk as the number of expected individual deaths is an easy way to communicate the damage. These concepts extend as well to the economic valuation of premature mortality.

Economists use a measure referred to as the ***value of a statistical life*** (VSL) to value changes in the risk of premature mortality. The VSL is calculated by dividing the WTP by the change in risk. For example, a WTP of $500 for a change in risk of premature death of 1/10,000 implies a VSL of $5,000,000. If 10,000 people are willing to pay $500 each to reduce their risk of dying by 1/10,000 then collectively they are willing to pay $5,000,000 so that one of them will not die prematurely. This is what is meant by the value of a statistical life. Multiplying the VSL times the number of premature deaths produces as a corresponding estimate of the economic damages.

The VSL coefficients are estimated by measuring people's willingness to pay (WTP) for a small reduction in the risk of dying prematurely. This methodology is used widely in valuing health outcomes for pollution control policies. Krupnick (2004) provides a review of some of these applications.

Krupnick et al (2002) surveyed a sample of people in Hamilton and estimated WTP to reduce their annual risk of death[10] by 5/10,000 and 1/10,000. The average household income and educational attainment of the people surveyed by Krupnick et al was similar to the Ontario average. The results of this survey were used since the study was based in Ontario and the risk reductions valued are comparable to the risk reductions in this analysis.

The change in the annual population-average premature mortality risk associated with the scenarios in this analysis is about 5/100,000 (i.e., 650 deaths/14,000,000, the approximate average size of the Ontario population at risk from 2007 to 2026 = a risk of 4.6/100,000). For the purposes of this analysis, the WTP estimated by Krupnick et al for an annual risk of premature death of 1/10,000 was used to value an annual risk of 1/20,000 (i.e., 5/100,000). This assumption likely produces an underestimate of the economic damages associated with premature mortality.

As the level of risk reduction decreases (i.e., as the incremental reduction in risk being valued becomes smaller), in general, willingness to pay for the reduction in risk decreases as well. However, this relationship is often not proportional (i.e., linear). People tend to be willing to pay more proportionally for reductions in risk where the reduction increments are small. For example, Krupnick *et al* found that their surveyed sample would typically spend no more than twice as much to reduce their risk of dying by a factor of 5 (from 1/1000 to 5/1000). Ideally, VSLs should be estimated for each scenario and for different groups within the population based on the expected changes in risk. Practically, however, this is not possible and average risk factors and VSLs have been used instead.

From a different perspective, the use of average VSLs means there is no distinction in valuing the risk of premature death according to income. While this may not be entirely consistent with the use of WTP as a measure of value, it does mean that the risk of premature death to all members of the affected population is valued equally.

Krupnick et al found that future risk reductions were valued less than more immediate risk reductions. In other words, future risk reductions were discounted relative to immediate risk reductions. Consequently, the present value of the WTP derived by Krupnick et al was estimated by discounting at 5% annually the corresponding inferred annual WTP payments. This present

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[10] Krupnick et al actually expressed the risk reductions in their survey as a 1/1,000 or 5/1,000 reduction spread evenly over 10 years which equates to an annual risk of 1/10,000 or 5/10,000.

value expression of the WTP was used to arrive at a VSL applicable to the cumulative premature deaths estimated in this analysis.

Assuming that the WTP for a 1/20,000 risk reduction is directly proportional to the WTP for a 1/10,000 reduction and using the results reported by Krupnick et al, a VSL of $4.18 million (CDN 2004$) was derived. This VSL tends to be on the low side of the estimates (Table 6-1). As a result, the estimates of economic damages in this analysis are likely on the low side. The low and high ranges are derived from the ranges reported by Krupnick et al using the same methodology.

Table 6-1 Published Estimates of the Value of a Statistical Life

Model or Study	Country/region	Value of Statistical Life [d]		
		Low	Medium	High
USA EPA (1999) [a]	**USA**	**$2.6**	**$7.9**	**$13.3**
US TAF/Boyd *et al* (1986)[b]	**USA**	**$2.6**	**$5.1**	**$10.1**
ExternE (1999) [a]	**Europe**		**$5.0**	
AQVM/Stratus (1999)	**Canada & USA**	**$2.8**	**$4.8**	**$9.6**
Krupnick *et al* (2002)[c]	**Hamilton**	**$3.0**	**$4.2**	**$5.1**

a: USA and European values from Krupnick (2004) and converted to CDN funds using Purchasing Power Parity of 0.80C$:1USD and annual CPI change of 2%.
b: TAF = Tracking and Analysis Framework (Bloyd et al. 1996), developed by a consortium of U.S. institutions, including RFF.
c: The scientific authority from which the VSL values used in this analysis were derived
d: All values are expressed as Canadian 2004$ Millions.

Pain and Suffering

Increased mortality and morbidity cause various types of damages. An important category of damage is the increased pain and suffering experienced by those afflicted with illnesses attributable to air pollution exposure. The economic value of pain and suffering is estimated using a similar approach to that described for valuing changes in the risk of premature mortality.

Stieb et al (2002) report the results of a survey of people experiencing pain and suffering from illnesses commonly associated with exposure to air pollution. These people replied to a series of questions regarding their willingness to pay to avoid the pain and suffering that they were experiencing. This methodology provided a good means to derive these estimates. The respondents were not valuing a hypothetical situation but were responding instead to an actual situation that they were experiencing at the time.

The total values reported by Stieb et al (2002) included not only allowance for pain and suffering but included as well, estimates for costs of treatment and lost productivity. The pain and suffering component of these estimates were used in this analysis. The estimates for emergency room visits included visits that led both to discharge and admission. These values were adjusted to estimate the proportion for emergency room visits that resulted in discharge only. The risk of increased hospital admission cases is accounted for separately. As well, all estimates were converted to 2004$. Table 6-2 provides the economic factors used in this analysis to account for pain and suffering.

Table 6-2 Pain and Suffering Economic Factors

Health Outcome		Pain and Suffering (2004$/case)		
General	**Specific**	**Low**	**Medium**	**High**
Premature Death	**All Types**	**$988**	**$1,252**	**$1,516**
Hospital Admission	**Respiratory**	**$1,004**	**$1,241**	**$1,477**
	Cardio-vascular	**$972**	**$1,264**	**$1,555**
Emergency Room Visit	**Respiratory**	**$490**	**$650**	**$841**
	Cardio-vascular	**$531**	**$675**	**$851**
Minor Illness	**Minor Restricted Activity Day**	**$0**	**$1**	**$2**
	Restricted Activity Day	**$7**	**$26**	**$46**
	Asthma Symptom Day	**$7**	**$18**	**$30**

Note, allowance is included for pain and suffering for both morbidity and mortality outcomes. The VSL estimates may include pain and suffering as well. If so some minor double counting might be present. On the other hand, the VSL estimates are more than three orders of magnitude greater than the pain and suffering factors so the impact of any double counting on the final net benefit estimates would be minor.

Cost of Treatment

The same cost of treatment economic coefficients that were derived by the Ontario Medical Association for air pollution-related illnesses were used in this analysis (DSS, 2000). These coefficients were converted to 2004$ to be consistent with the other economic factors used in this analysis. Table 6-3 provides simple average costs of treatment for three age groups

The overall costs of treating air pollution-related illnesses was calculated by multiplying the expected number of cases of a particular illness in a particular local area by the corresponding local treatment costs for that particular illness and age of person.

Value of Lost Productivity

Estimates of lost time caused by certain types of illnesses were included. The lost time varies with the severity of the illness. As well, allowance is made for lost time of non-paid caregivers. Table 6-4 provides a summary of the lost time factors for various illnesses.

Table 6-3 Provincial Average Costs of Treatment by Illness Type[11] and Age Group

Health Outcome		Healthcare Costs of Treatment (2004$/day)		
General	Specific	Children (Less than 19)	Adults (19 to 65)	Seniors (Greater than 65)
Premature Death	All Types Average	$492	$684	$855
Hospital Admission	Respiratory	$520	$689	$890
	Cardio-vascular	$465	$680	$819
Emergency Room Visit	Respiratory	$87	$87	$87
	Cardio-vascular	$87	$87	$87

Table 6-4 Average Number of Lost Days by Illness Type[12]

Health Outcome		Lost Days (number of days/case)	
General	Specific	Patient	Care-giver
Premature Death	All Types	4.5	1
Hospital Admission	Respiratory	13	3
	Cardio-vascular	8	2
Emergency Room Visit	Respiratory	2	1
	Cardio-vascular	1	1
Minor Illness	Minor Restricted Activity Day	0	0
	Restricted Activity Day	1	0
	Asthma Symptom Day	1	0

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[11] Note, no health care cost of treatment factors are shown for minor illnesses. These minor illnesses do not require institutional care by definition.

[12] Lost productivity factors differ by age group for both patients and caregivers. The values shown in this table are for adults. The values for adults and children are higher but the lost of time for children and seniors is valued at zero since they are out of the work force. This assumption underestimates the value of this lost time.

The value of lost productivity was calculated by multiplying the number of lost days times the average wage rate. The original average wage rates were updated using the average wage in Ontario for 2003 (i.e., from $39/day to $133/day for males and from $26/day to $77/day for females[13]). These wage rates were adjusted to 2004$.

Similar to the case with pain and suffering, lost time may have been included in estimates of VSL. Nonetheless, an allowance for lost time even in the case of premature mortality is included. Doing so may lead to some double counting but the impact is insignificant relative to the magnitude of the VSL coefficient.

6.1.6 Uncertainty Analysis

A Monte Carlo simulation routine was used to estimate upper and lower ranges for estimated damages. A key issue when estimating uncertainty ranges is the level of independence that is assumed with respect to the variation among individual parameters. Where a high level of independence is present, variations among parameters tend to cancel each other out to a certain extent. On the other hand, when the variation among parameters is interdependent (i.e., their variation is connected and behave similarly), the variations are additive, leading to wider uncertainty ranges.

Much care has been taken in selecting the epidemiological studies on which to rely with particular attention being given to the methodologies used to minimise problems of covariance. While covariance can never be totally eliminated, statistical techniques can be used to minimise its influence on estimated risk factors. This is an issue that has received much attention in the epidemiological literature.

For the purposes of this analysis, variation among the parameters is assumed to be independent. Variations in health risk parameters are not expected to demonstrate a high degree of covariance for the reasons mentioned.

6.2 Estimated Damages

Following is a summary of the health and associated economic damages estimated for each of the four scenarios.

Health Effects

Table 6-5 provides a summary of the health effects resulting from the air pollutant emissions associated with each scenario. Premature mortality estimates based both on time series and cohort risk factors are included. The time series-based estimates are provided for reference purposes only. Many previous air pollution damage analyses have reported primarily time series-based premature mortality rates. Therefore, these estimates will provide a gauge by which to compare the reasonableness of these estimates relative to other health damage estimates. As noted in Section 6.1.4, the cohort-based risk factors are more relevant for this analysis.

The cohort-based premature risk factors result in estimated premature deaths about seven times greater than those estimated using time-series risk factors. In other words, using time-series risk factors underestimates actual damages associated with premature mortality by about seven times[14]. Using the cohort-based risk factors influences economic damage estimates significantly since premature death accounts for the highest economic losses on a per-case basis.

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[13] Average wage rates varied by age groups. These values represent the range of average wage rates for the age groups used in the health risk analysis.

[14] The economic losses that would correspond to acute premature mortality damages can be approximated by dividing the cohort-based economic losses by seven.

An average annual total of about 660 premature deaths, 920 hospital admissions, 1,090 emergency room visits and 331,200 minor illness cases could be avoided by switching from the Base Case (Scenario 1) to Nuclear/Gas (Scenario 3) in 2007. Even so, emissions associated with Scenario 3 (Nuclear/Gas) are still expected to contribute to a total of 5 premature deaths, 12 hospital admissions, 15 emergency room visits and 2,500 minor illness cases per year. The health impacts of Scenario 2 (All Gas) are about double those with Scenario 3 (Nuclear/Gas) while the health impacts of Scenario 4 (Stringent Controls) are considerably greater than those associated with Scenario 3 (Nuclear/Gas) but are well below those with Scenario 1 (Base Case).

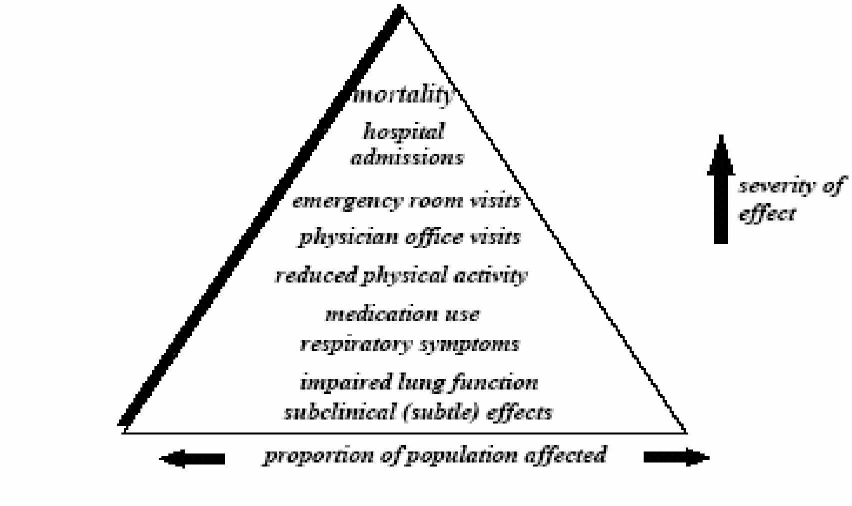
As expected, the proportions of estimated illnesses follow the general pattern of the health effects pyramid (Figure 6.1; American Thoracic Society, 1985). The frequency of the estimated number of cases of each illness type generally increases as the severity of the illness decreases. The proportion of premature mortality cases based on cohort risk factors appears to be somewhat high when using the crude health pyramid guideline. This raises an important consideration when interpreting these results.

Table 6-5 Average Annual Health Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Premature Deaths (Total)	**668**	**11**	**5**	**183**
Premature Deaths (Acute)	103	2	1	28
Hospital Admissions	**928**	**24**	**12**	**263**
Emergency Room Visits	**1,100**	**28**	**15**	**312**
Minor Illnesses	**333,660**	**5,410**	**2,460**	**91,360**

Relative risks derived from comprehensive long-term cohort analyses are only available for premature mortality. The risk factors for the other health endpoints are based on time series studies or short-term cohort studies in the case of some minor illness studies. As a result, these risk estimates suffer from the same limitations as do premature mortality risk factors derived from time series studies. Longer-term health effects are not included. For this reason, the health damage estimates derived from time series-based risk factors underestimate actual risks, particularly those associated with longer-term exposure and delayed responses to exposure. No allowance has been made for this weakness in the risk factors used in this analysis; however, simple logic suggests that the proportional relationship between cohort and time-series premature mortality risk factors may well apply for other health risks as well.

Figure 6.1 Health Effects Pyramid



Given the high value people assigned to the risk of premature mortality (i.e., VSL), the premature mortality estimates play a dominant role in the economic damage estimates associated with these health outcomes. For this reason, this health category was examined in further detail.

Over 80% of the premature deaths are associated with the elderly (i.e., age 65+). This age group is recognised as being at high risk from exposure to air pollution (Schwartz, 2003). The remainder of the deaths occur in adults. Premature mortality in the under-19 age group is negligible; although, epidemiological evidence exists that suggests that young children (in particular, young babies) are also vulnerable to premature mortality (Loomis et al, 1999). This high at-risk group is not addressed in this analysis since no corresponding cohort-based risk factors are available.

These results demonstrate the higher health risks associated with continuing to use CFG technology. Significant reductions in the risk of many adverse health outcomes can be achieved by converting to other forms of electricity generation (e.g., Scenarios 2 or 3). Scenario 3 (Nuclear/Gas) offers the greatest opportunity to reduce health risks; however, these estimates do not include any allowance for the health risks associated with nuclear power generation. These risks would need to be added to obtain a full understanding of the relative risks associated with each of the alternatives.

6.2.1 Economic Damages

While the number of cases of different illnesses cannot be added together (e.g., one cannot reasonably add premature death and minor illness cases together), summing the economic damages associated with each health endpoint is appropriate to derive an estimate of overall economic damages. The overall economic damages reported were derived by calculating the economic damages associated with each health endpoint and adding these values together.

Table 6-6 provides the results of these calculations. These totals are derived from the cumulative health damages expected to be incurred over the forecast horizon (i.e., 2007 to 2026). The annual damages have been discounted to arrive at a total present value estimate. Note, the values shown in Table 6-6 are expressed in millions of 2004 dollars.

Table 6-6 Present Value of Health Damages

	SCENARIO			
	1 Base Case	2 All Gas	3 Nuclear/ Gas	4 Stringent Controls
Premature Deaths - Total	**$33,963**[a] ($5,238)[b]	**$4,361** ($672)	**$4,103** ($632)	**$12,125** ($1,873)
Hospital Admissions	**$76**	**$11**	**$10**	**$28**
Emergency Room Visits	**$15**	**$2**	**$2**	**$6**
Minor Illnesses	**$88**	**$13**	**$12**	**$32**
TOTAL[c]	**$34,142** ($5,417)	**$4,387** ($698)	**$4,127** ($657)	**$12,191** ($1,939)

a: All values expressed as 2004$ Millions.
b: Values shown in brackets are based on acute premature mortality damage estimates.
c: Column totals may not add up exactly due to rounding.

The dominant effect of the economic damages associated with premature mortality is clearly evident. Economic damages associated with premature mortality commonly dominate air pollution damage estimates (DSS, 2000).

Table 6-7 expresses these results using three economic measures. The levelised cost provides a measure of the economic damages associated with adverse health effects arising from each MWh of electricity generated.

6.2.2 Mercury Damages

No rigorous quantitative estimates of the potential health damages associated with the four scenarios were developed. However, some definitive qualitative statements can be made. As shown in Table 5-1, Scenario 1 (Base Case) produces the highest mercury emissions. Scenario 4 (Stringent Controls) produces about 75% less mercury emissions. Scenarios 2 (All Gas) and 3 (Nuclear/Gas) produce no mercury emissions. On this basis alone, it can be concluded that Scenario 1 and, to a somewhat lesser extent, Scenario 4 produce health risks from mercury exposure, that do not occur with Scenarios 2 or 3.

The challenge is to estimate the types and magnitude of these health risks. The types of adverse health effects associated with mercury exposure are well understood as reviewed in Section B.6. Quantifying these risks in terms of the amount of mercury emitted from any one source is much more challenging. No sufficiently accurate estimation methodology and inadequate data are available to produce quantitative estimates of mercury health risks for Ontario.

Table 6-7 Total, Annualised and Levelised Health Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Total Present Value ($Billions)	**$34** ($5.4) [a]	**$4** ($0.7)	**$4** ($0.7)	**$12** ($1.9)
Annualised Damages ($Millions)	**$3,020** ($479) [a]	**$388** ($62)	**$365** ($58)	**$1,079** ($172)
Levelised Damages ($/MWh)	**$113** ($18)	**$15** ($2)	**$14** ($2)	**$40** ($6)

a: Values shown in brackets are based on acute premature mortality damage estimates.

7 ENVIRONMENTAL DAMAGES

Air pollutants from CFG facilities are known to cause various types of environmental damages including corrosion of materials, vegetation damage, acidification of aquatic and terrestrial ecosystems, and global climate change. This CBA only includes environmental damages caused by ozone and PM_{10} to household materials (i.e., soiling) and agricultural production losses (i.e., for wheat, tobacco, corn, and soybean). The physical impacts of GHG emissions were not estimated but economic damages were approximated on a "cost of control" basis.

This section discusses the methodology used to estimate these physical and economic damages, information sources and the results of the analysis.

7.1 Methodology

Emissions of SO_X, NO_X, particulate matter ($PM_{2.5}$, PM_{10}), and greenhouse gasses were estimated for each generating facility (see Table A-1 to Table A-4 in Appendix A). The CALPUFF model was used to estimate ambient air quality (i.e., for PM_{10} and ozone) at a census division level of spatial resolution. These air quality forecasts were used in the Air Quality Valuation Model (AQVM) to generate physical and monetary estimates of damages to household materials and to agricultural production. The technical details of the damage functions used in the AQVM are described in the supporting technical documentation (Stratus Consulting, 1999). These damage functions were based on the most reliable literature available when the last public version of the model was released in 1999. Updated damage functions have not been added to the AQVM since, although Environment Canada is working on developing alternate methodologies to produce estimates for similar damage categories (Yves Bourrassa, 2005, personal communication). This study relied on the default damage functions in the 1999 version of the AQVM.

The AQVM includes economic factors to monetise air pollution damages. The technical derivation and scientific support for these factors are set out in the technical documentation (Stratus Consulting, 1999). The economic damage estimates were converted to 2004$. Otherwise, the default economic factors in the AQVM were used to estimate monetary damages.

7.1.1 Soiling of Household Materials

PM causes soiling when it is deposited on household materials (e.g., clothing). The AQVM damage function is based on the number of households in each CD. It is assumed that the amount of receptor (i.e., household materials) is directly proportional to the number of households. Manuel et al (1982), Watson and Jaksch (1982), and McClelland et al (1991) report quantitative relationships between changes in PM concentration and soiling rates including increased cleaning costs. The AQVM contains a default set of damage functions derived from these sources. These default functions were used in this analysis.

The AQVM includes an estimate of the numbers of households in each CD and the expected change over time. These estimates are based on 1996 census data. Damages estimates were produced for 2004 and were assumed to remain constant over the forecast horizon.

7.1.2 Agricultural Crop Damages

Ozone is a well known oxidant that causes leaf damage with sensitive crops. The amount of damage is a function of the timing, duration, concentration and sensitivity of the exposed vegetation. Crop-specific concentration-response functions derived from work by Heagle et al (1988) are included in the AQVM. As well, the area planted in each crop type in Ontario is included in the AQVM. This analysis used these default data in the AQVM. Some changes in agricultural cropping patterns have occurred since these data were collected.

Default production costs and crop prices based on 1993 to 1995 statistics (except for tobacco costs and prices which are based on 1990 to 1995 data) are included in the model. These default data were used as is.

These default values were combined with the forecast changes in ambient ozone concentrations to derive estimates of the expected attributable yield loss. These yield losses were combined with the net value estimates for each crop (i.e., selling price minus production costs) to derive a corresponding estimate of annual monetary damages that was then applied uniformly for each year in the forecast horizon. Note, the AQVM methodology assumes that air pollution does not lead to a change in cost (e.g., as a result of farmers investing in mitigative measures) and that farmers take no action in the future (e.g., use more resistant strains and varieties) to avoid or minimise the impacts of air pollution.

7.1.3 Greenhouse Gas Damages

Action is occurring at a global scale to curb GHG emissions. These initiatives are being taken to reduce the rate of climate change. The concern is that climate change will have far reaching and long lasting impacts on the environment and human economies.

From a CBA perspective, the ideal approach would be to develop an emissions/response function that could be used to predict the marginal impact of each additional tonne of GHG emitted[15]. Practically however, some major conceptual and methodological barriers prevent such an approach being implemented. In terms of economic principles, CBA is valuable for

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[15] Ideally, the GHG emissions being assessed should be based on a life-cycle perspective, particularly where the supply of inputs to the production process (i.e., electricity generation) or the disposal of production wastes have external costs (e.g., environmental damages) not reflected in prices. For example, GHGs are associated with the production of natural gas (e.g., leakage during recovery and transport, burning of impurities) and the impact of these emissions is not captured in the damage estimates in this report. However, the same principles apply with coal production. Conducting a comprehensive life cycle analysis for all of the production inputs and wastes was beyond the scope of this CBA.

valuing small (marginal) changes within an economy. However in the case of large scale changes over long time periods, the underlying basic assumptions about prices, costs and preferences on which CBA is founded are violated. The threat of climate change is hardly a marginal change in the environment. Climate change has the potential to disrupt local economies and cause widespread and large shifts in prices. For this reason using CBA to value the risks of climate change is questionable.

Practically, assessing the impact of relatively small quantities of GHG emissions is problematic. The dynamics of climate change are quite complicated and difficult to predict, let alone trying to predict the impacts of climate change on the environment and human economies. When the impact being predicted is relatively small, some gross averaging assumptions need to made that are essential unverifiable. Combining this environmental uncertainty with the economic theory problems makes the CBA approach of limited value for valuing relatively small changes in GHG emissions.

While attempts to estimate the marginal environmental damages of GHG emissions have been made (e.g. Pearce, 2003), an alternate approach has been adopted in this analysis. The value of avoided GHG emissions has been equated to the expected trading price of GHG permits. This trading price will be driven by the regulatory limits placed on GHG emissions through international agreements like the Kyoto Protocol and the costs of control and carbon sequestration. In this type of situation, the costs of control will set the price and do represent an appropriate approximation for use in CBA.

Under the Kyoto Protocol, Canada is committed to targeted GHG reductions by the commitment period of 2008-2012. The Canadian mechanisms for achieving these GHG reductions have not yet been formalized though an emission trading system is likely. The Government of Canada has negotiated an agreement with industrial producers to cap their per-tonne costs of reducing costs of greenhouse gas emissions at no more than $15/tonne during the commitment period (http://www.nrcan-rncan.gc.ca/lfeg-ggef/English/faq_en.htm). Consequently, each avoided tonne of GHG will save polluters as much as $15 (i.e., this is the amount that the polluter would otherwise have been forced to spend for each tonne of GHG emitted).

Of course, $15/tonne is an upper limit. If GHG control technologies or measures can be installed and operated/implemented for less than $15/tonne, then the trading price could be less than $15/tonne. For this reason, GHG permit prices of $15/tonne to $10/tonne over the commitment period were examined as part of this analysis.

After 2012, the government has not committed to cap the cost of greenhouse gas reductions. Beyond 2012, permit prices will be driven by technology costs and any further GHG reduction targets. What control and sequestration technologies may emerge between now and then is difficult to predict. As a result, a broader range in permit prices has been analysed. A $15/tonne price has been used for the post 2012 period. However, a range of prices from $5 to $30/tonne was used in the sensitivity analysis to explore the possible effects on the overall net benefit estimates.

7.2 Estimated Damages

This section discusses the environmental damage estimates derived using the methodology described above. As well, environmental damages associated with mercury emissions are examined.

7.2.1 PM and Ozone Damages

Table 7-1 presents the estimated economic damages associated with the three environmental damage categories discussed. Note the order of magnitude difference among the economic estimates for each damage category. GHG damages dominant the total damage estimate.

The differences among the scenarios are quite pronounced. Scenario 1 (Base Case) is estimated to have the greatest impact on materials soiling and crop damage. Scenario 4 (Stringent Controls) has a similar impact as Scenario 1 in terms of damages associated with GHG emissions but shows marked improvements in materials soiling damages and crop damages. Indeed, estimated crop damages with Scenario 4 are less than with Scenarios 2 (All Gas) and 3 (Nuclear/Gas).

As mentioned, the GHG damage estimates dominate the overall damage total. For this reason, Scenario 3 (Nuclear/Gas) is estimated to have the lowest total environmental damage of the four scenarios (given the scope of environmental damages included in the study). Scenario 3 (Nuclear/Gas) has the lowest GHG emissions.

Table 7-1 Present Value of Environmental Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
GHG Permits (2004$ Billions)	**$4.0**	**$1.6**	**$0.5**	**$4.0**
Crop Damages (2004$ Thousands)	**$94**	**$56**	**$56**	**$31**
Materials Soiling (2004$ Millions)	**$230**	**$7**	**$3**	**$63**
Total (2004$ Billions)	**$4.2**[a]	**$1.6**	**$0.5**	**$4.0**
a: Column totals may not add up exactly due to rounding.				

Table 8-1 presents the total environmental damages for the four scenarios expressed as total present value, average annualised damages and levelised damages. Comparing these results with those for health damages (see Table 6-7), the overall importance of the health damages relative to environmental damages is clear.

7.2.2 Mercury Damages

Similar to the situation with health damages associated with mercury exposure, no rigorous quantitative estimates of the potential environmental damages associated with the four scenarios were developed. On the other hand, the same qualitative conclusions reached with respect to health damages are applicable for environmental damages as well.

The types of adverse environmental effects associated with mercury exposure are well understood as reviewed in Section B.2. Quantifying these risks in terms of the amount of mercury emitted from any one source is much more challenging.

8 COSTS AND BENEFITS

This section brings together all of the results discussed in the preceding sections and provides a detailed examination of these results from various perspectives.

8.1 Total Cost of Generation

Combining the financial costs with the estimates of health and environmental damages provides an estimate of the total cost of the electricity generation associated with each scenario. This total cost is the minimum value that the electricity must be worth to society to warrant its production and provides a minimum average base price that should be charged if the full costs of generation were to be captured through the market price.

Table 8-1 Total, Annualised and Levelised Environmental Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Total Present Value ($Billions)	**$4.2**	**$1.6**	**$0.5**	**$4.0**
Annualised Damages ($Millions)	**$371**	**$141**	**$48**	**$356**
Levelised Damages ($/MWh)	**$13.92**	**$5.29**	**$1.77**	**$13.37**

Table 8-2 presents the total cost of generation estimated for each scenario. The highest cost of generation is associated with Scenario 1 (Base Case). Its costs of generation are more than double the costs for the least-cost scenario, namely Scenario 3 (Nuclear/Gas). The total cost of generation for Scenarios 2 (All Gas) is somewhat less than for 4 (Stringent Controls). The total cost of generation for Scenarios 2 and 4 are greater than those for Scenario 3 by about 34% and 44% respectively.

A breakdown of the cost components making up the total cost of generation is included. The relative contribution of the components varies significantly among the scenarios. With Scenario 1 (Base Case), health damages comprise 77% of the total cost of generation; whereas, with Scenarios 2 (All Gas) and 3 (Nuclear/Gas), financial costs comprise about 80% of the total costs of generation. Scenario 4 (Stringent Controls) is intermediate between these two extremes (i.e., 51% of the total cost comprises health and environmental damages).

These proportions are a good measure of a fundamental difference among the scenarios. Scenarios 1 (Base Case) and 4 (Stringent Controls) involve relatively low financial costs and relatively high health and environmental damages. Scenarios 2 (All Gas) and 3 (Nuclear/Gas) are the opposite. In other words, Scenarios 1 and 4 involve a substitute of health and environmental damages in favour of greater financial costs (in particular capital investment in new generation facilities). This difference raises a profound public policy principle that needs to be carefully weighed when considering these scenarios.

CBA is a useful analytical tool to compare alternative courses of action. The results of this analysis provide useful guidance for decision-making but do not deal with all facets that need to be considered. One facet which CBA does not address is the most appropriate distribution of costs and benefits among Ontarians; this distribution varies significantly from one scenario to another. The proportion of health and environmental damages is just one indicator of the differences in the distribution of costs and benefits among the scenarios. Those most likely to suffer the impacts of air pollution (i.e., the young and the elderly) are not necessarily those with the most to gain by avoided financial costs of generation.

Table 8-2 Annualised Financial Costs and Health and Environmental Damages

	SCENARIO			
	1 Base Case	**2 All Gas**	**3 Nuclear/ Gas**	**4 Stringent Controls**
Financial Costs	**$ 985**[a]	**$ 2,076**	**$ 1,529**	**$ 1,367**
Health Damages	**$3,020** ($479)[b]	**$388** ($62)	**$365** ($58)	**$1,079** ($172)
Environmental Damages	**$371**	**$141**	**$48**	**$356**
Total Cost of Generation	**$4,377** ($1,836)	**$2,605** ($2,279)	**$1,942** ($1,635)	**$2,802** ($1,895)
Health and Environmental Proportion	**77%** (46%)	**20%** (9%)	**21%** (6%)	**51%** (28%)

a: All values are expressed as annualised costs/damages in 2004$ Millions.
b: Values shown in brackets are based on acute premature mortality damage estimates.

Table 8-3 provides the total cost of generation estimates for each of the scenarios expressed as a total present value, annualised cost and levelised cost.

Table 8-3 Total Cost of Generation

	SCENARIO			
	1 Base Case	2 All Gas	3 Nuclear/ Gas	4 Stringent Controls
Total Present Value ($Billions)	**$49** ($21) [a]	**$29** ($26)	**$22** ($18)	**$32** ($21)
Annualised Costs ($Millions)	**$4,377** ($1,836)	**$2,605** ($2,279)	**$1,942** ($1,635)	**$2,802** ($1,895)
Levelised Costs ($/MWh)	**$164** ($69)	**$98** ($86)	**$72** ($61)	**$105** ($71)
a: Values shown in brackets are based on acute premature mortality damage estimates.				

8.2 Estimated Net Benefits

Net benefit (or cost) using the CBA methodology employed in this study is the difference in the total cost of generation for a given scenario relative to the total cost of generation for the reference case (i.e., Scenario 1 – Base Case). This difference represents the cost savings that might be realised by changing from the status quo to a given alternative.

Table 8-4 provides a summary of the net benefits for each of the three scenarios. Scenario 3 (Nuclear/Gas) is estimated to yield the largest net benefit of the three scenarios. Based on these estimates, the province would realise an average annual net benefit of $2.4 billion by switching from the current CFG generation technology and adopting a combination of nuclear and gas generation.

Table 8-4 Estimated Net Benefits

	SCENARIO		
	2 All Gas	3 Nuclear/ Gas	4 Stringent Controls
Present Value ($Billions)	**$20** (-$5.0) [a]	**$28** ($2.3)	**$18** (-$0.7)
Annualised ($Millions)	**$1,772** (-$443)	**$2,435** ($201)	**$1,575** (-$59)
Levelised ($/MWh)	**$67** (-$16.7)	**$91** ($7.5)	**$59** (-$2.2)
a: Values shown in brackets are based on acute premature mortality damage estimates.			

Scenario 2 (All Gas) is estimated to yield the next highest annual net benefit (i.e., $1.8 billion per year). The net benefit of Scenario 2 is about 25% less than that estimated for Scenario 3 (Nuclear/Gas). Scenario 4 (Stringent Controls) is estimated to yield the lowest net benefit among the three alternatives analysed (i.e., $1.6 billion). However, the difference in net benefit between Scenarios 2 and 4 is minor given the nature of this analysis and might easily flip one way or another with relatively small changes in key coefficients (see Section 8.4 for further analysis of this nature). On the other hand, the total cost of generation for of Scenario 4 (Stringent Controls) is more likely to increase due to gaps in the health and environmental damage estimates. Filling these gaps would likely increase the difference between Scenario 4 and Scenarios 2 and 3. For now, Scenarios 2 (All Gas) and 4 (Stringent Controls) should be considered comparable in terms of these net benefit estimates.

If only the economic damages associated with acute premature mortality risks are used to estimate net benefit, both Scenarios 2 (All Gas) and 4 (Stringent Controls) would yield annual net loses relative to the Base Case. Scenario 3 (Nuclear/Gas) would yield a positive annual net benefit of $200 million per year.

These net benefit estimates involve significant gaps and uncertainties. These results need to be interpreted carefully with full consideration given to the potential effects of these gaps and uncertainties (see Section 9.1 for further discussion of these limitations). For example, in the case of Scenario 3 (Nuclear/Gas), no allowance is included for health and environmental risks associated with nuclear power generation. The net benefit estimates for each scenario capture only some of the costs and benefits. The potential magnitude of the omitted costs and benefits should be considered when the scenarios are being compared among themselves.

8.3 Uncertainty Ranges

This uncertainty analysis is based only on the statistical error ranges for the health risk factors. These error ranges are based on the reported statistical confidence ranges for the various health risk factors.

Table 8-5 provides a summary of the uncertainty ranges for the net benefit estimate for each scenario. The same uncertainty ranges were used for all health risk factors when the health damages were estimated for each scenario. However, the uncertainty ranges for some health endpoints are broader than they are for others. This accounts for the differences in the ranges among the scenarios.

A positive net benefit is estimated for the three scenarios over the entire uncertainty range. Scenario 3 (Nuclear/Gas) is estimated to yield the largest net benefit over all ranges; however, the difference between Scenarios 3 (Nuclear/Gas) and 4 (Stringent Controls) declines from about $860 million to approximately $510 million annually with the low range of estimates. The ranking of Scenarios 2 (All Gas) and 4 (Stringent Controls) flips at the low end of the range. The difference in net benefit between these two scenarios goes from about $200 million in favour of Scenario 2 using the mean estimate to $140 million in favour of Scenario 4 with the low range.

Table 8-5 Net Benefit Uncertainty Ranges

	SCENARIO		
	2 All Gas	**3 Nuclear/ Gas**	**4 Stringent Controls**
Lower Range	**$491** [a]	**$1,143**	**$630**
Mean	**$1,772**	**$2,435**	**$1,575**
Upper Range	**$2,946**	**$3,620**	**$2,440**

a: All values are expressed as annualised net benefits in 2004$ Millions.

The high range estimates exhibit the opposite trend. The difference between Scenarios 3 and 4 increases to about $1.2 billion annually. The difference between Scenarios 2 (All Gas) and 4 increases to about $510 million. The difference between Scenarios 2 and 3 is not affected substantially at the high end of the uncertainty ranges.

The potential for the net benefits among Scenarios 2 and 4 to flip is evident from this analysis. On the other hand, the performance of Scenario 3 (Nuclear/Gas) relative to the other two scenarios is consistent and is not likely to change due to uncertainties in the health risk factors.

8.4 Sensitivity Analysis

Sensitivity analysis differs from the uncertainty analysis presented in the preceding section. Unlike uncertainty analysis, sensitivity analysis is not based on statistical principles. Instead, sensitivity analysis involves strategically selecting key parameters and varying them over a range of values to see their influence on the CBA results.

Sensitivity analysis can be performed using several methods. Two methods were used in this analysis. The first involves varying one parameter at a time while keeping all other parameters at their mean or best estimate value. The second method is to vary two or more parameters together at the same time. With this second method, the potential for sensitivity analysis combinations is essentially infinite. As a result, judgement is required to identify a suite of sensitivity combinations that will provide reasonable insight into the significance of various combinations of parameters.

Four key parameters were selected for the sensitivity analysis. Following are the ranges of values tested for each parameter:

- Social Discount Rate (3% - 10%)
- Gas Fuel Price Base Rate ($6 - $9) and Rate of Increase (0% - 2%)[16]
- GHG Permit Price ($5 - $30)
- Value of a Statistical Life ($3.0 - $5.1 million).

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[16] Gas fuel prices and rate of increase were changed at the same time. When the gas price was set at the low range so too was the rate of increase and vice versa.

8.4.1 Single Parameter Sensitivity Analysis

Table 8-6 provides the results of the sensitivity analysis using the first method (i.e., changing one parameter at a time). These results are provided only for Scenario 3 (Nuclear/Gas). However, the estimated net benefits for the other scenarios follow a similar pattern. With all parameter values tested, Scenario 3 (Nuclear/Gas) is consistently r the largest net benefit of the three scenarios.

Table 8-6 Single Parameter Sensitivity Analysis Results for Scenario 3 (Nuclear/Gas)

	Scenario 3 - Nuclear/Gas[a]	
Sensitivity Parameter	**Low Range**	**High Range**
Social Discount Rate	**$3,216[b]**	**$1,232**
Gas Fuel Price	**$2,501**	**$2,172**
GHG Permit Price	**$2,268**	**$2,630**
Value of a Statistical Life	**$1,684**	**$3,047**

a: The mean annualised net benefit for Scenario 3 (Nuclear/Gas) is $2,435 million.
b: All values are expressed as annualised net benefits in 2004$ Millions.

The estimated net benefit for Scenario 3 (Nuclear/Gas) is least sensitive to assumptions made concerning fuel prices and GHG permit prices. The net benefit varied by less than 15% from the mean estimate when these parameters were varied over the ranges indicated.

Conversely, the net benefit estimate varied by just under 30% when the VSL coefficient was varied .by about 25%. Scenario 3 (Nuclear/Gas) is estimated to account for a relatively low number of attributable premature deaths; however, the net benefit is measured relative to Scenario 1 (Base Case). Scenario 1 does have a large number of attributable deaths which can be avoided with Scenario 3. This is the reason for the sensitivity of Scenario 3 (Nuclear/Gas) to the VSL estimate. Given these results, considerable care is warranted to ensure that the best possible estimate of VSL is used in this analysis.

The net benefit estimate exhibited the greatest sensitivity to the social discount rate. The net benefit varied by almost 40% when the social discount rate was varied. However, the range in social discount rates tested was proportionately greater than for the other parameters (i.e., a variation of 100% at the high end). As is the case with VSL, choosing the most appropriate social discount rate needs to be done carefully.

8.4.2 Parameter Combinations Sensitivity Analysis

The second method of sensitivity analysis involves varying combinations of parameters simultaneously. For this purpose, logical combinations of parameters were devised that might reflect different “world views”. Three world views were devised (i.e., favour the status quo, precautionary and favour change). The specifics of these three cases are as follow:

- ***Favour the status quo*** – This combination of parameters has been designed to yield a result most likely to favour continuing operation of the province’s CFG facilities (i.e., Scenario 1 – Base Case). The parameter values for this case are:

  - High social discount rate (which favours current benefits and costs relative to longer-term benefits and costs),
  - High gas fuel prices (which would increase the costs of Scenarios 2 (All Gas) and 3 (Nuclear/Gas)),
  - Low GHG permit prices (implying that GHG damages would be less than currently predicted and/ or that technological developments will lead to lower permit prices, either of which will favour Scenario 1 (Base Case) and to a lesser extent, Scenario 4 (Stringent Controls)), and
  - Low VSL value (which diminishes the importance of premature deaths that are largely associated with CFG emissions).
- ***Precautionary*** - This combination of parameters has been designed to reduce the possibility that costs are underestimated and/or that benefits are overestimated. This combination does not clearly favour one scenario or another. The parameter values for this case are:
  - Low social discount rate (which reduces the possibility that future costs and damages will be prove to be relatively more important or greater than estimated),
  - High gas fuel prices (which reduces the possibility that gas fuel costs are underestimated),
  - High GHG permit prices (which reduces the possibility that GHG damages would are underestimated), and
  - High VSL value (which diminishes the possibility of underestimating the value society assigns to increased risk of premature mortality).
- ***Favour change*** - This combination of parameters has been designed to yield a result most likely to favour closing the province's CFG facilities and moving toward alternate fuels, in particular gas and nuclear (i.e., Scenarios 2 – All Gas and 3 – Nuclear /Gas). The parameter values for this case are:
  - Low social discount rate (which increases the importance of future health and environmental damages compared to current financial costs),
  - Low gas fuel prices (which would make the two gas scenarios less costly),
  - High GHG permit prices (which increases the significance of GHG damages that are largely associated with the coal scenarios), and
  - High VSL value (which increases the importance of premature deaths that are largely associated with CFG emissions).

Table 8-7 provides the results for each of these sensitivity analysis combinations.

As would be expected, the range of results is greater with the combinations of sensitivity analysis parameters. The "Favour the status quo" combination results in a lower total cost of generation for Scenario 1 (Base Case) compared to the best estimate combination of parameters; a not surprising result since this combination of parameter values was designed with this intent in mind. The overall effect is that the estimated net benefit for Scenarios 2 (All Gas) and 3 (Nuclear/Gas) are reduced significantly. Indeed with this combination, Scenario 2 is estimated to yield a net loss (i.e., a loss of $106 million per year) rather than a net benefit. Scenario 4 (Stringent Controls), which is most similar to Scenario 1 (Base Case), exhibits much less sensitivity to this combination of parameters compared to Scenarios 2 and 3. Nonetheless, Scenario 3 (Nuclear/Gas) is estimate to still yield a slightly larger net benefit than Scenario 2 (i.e., by about $58 million per year).

Table 8-7 Results of Sensitivity Analysis Combinations

	SCENARIO		
	2 All Gas	**3 Nuclear/ Gas**	**4 Stringent Controls**
Best Estimate	**$1,772**	**$2,435**	**$1,575**
Favour Status Quo	**- $106**	**$651**	**$593**
Precautionary	**$1,900**	**$3,155**	**$2,125**
Favour Change	**$2,858**	**$3,491**	**$2,125**

a: All values expressed as annualised costs in 2004$ Millions.

The "Precautionary" combination results in estimated net benefits that are proportionately similar to those estimated with the "Best estimate" case; however, the net benefits of all three scenarios are higher than the best estimate values. As well, the net benefit for Scenario 4 (Stringent Controls) is estimated to exceed slightly the net benefit of Scenario 2 (All Gas).

The final combination ("Favour change") results in a significant increase in the net benefits of Scenarios 2 (All Gas) and a somewhat lesser impact with Scenario 3 (Nuclear/Gas). The estimated net benefit for Scenario 4 (Stringent Controls) is the same with both the "Precautionary" and "Favour Change" combinations.

The results of both sets of sensitivity analyses show that the ranking of the scenarios in terms of estimated net benefit is stable. Scenario 3 (Nuclear/Gas) consistently is estimated to yield the greatest net benefit among the three scenarios.

The reasonableness of the specifications for the parameters with each of these combinations needs to be carefully considered. Certainly, the parameter values specified for each combination represent an extreme set of assumptions. However, even with these extreme values, Scenarios 3 and 4 are consistently estimated to yield a positive net benefit relative to the status quo (i.e., Scenario 1). Scenario 2 (All Gas) could result in a net loss under the one set of parameter combinations; although a significant upside risk for yielding a significantly greater net benefit than the best estimate value also exists with this scenario.

9 LIMITATIONS AND RECOMMENDATIONS

This section examines some key limitations in the CBA presented in the preceding sections. These limitations should be carefully considered when interpreting the results of this analysis. As well, recommendations are offered that could be implemented to improve the scope and accuracy of the estimates of costs and benefits.

9.1 Gaps and Key Assumptions

This section examines a number of gaps in this CBA. These gaps are largely due to limitations in information and scientific understanding. The quantitative impacts of these gaps on estimated net benefits have not been estimated. However, the likely impacts are described qualitatively. When considering the quantitative estimates of net benefit, these gaps should be carefully considered as well.

9.1.1 Air Pollution Modelling

The air pollution methodology uses observed weather conditions for 1999 to represent future average weather conditions over the forecast horizon. On a short-term basis, weather is highly variable and conditions will vary significantly from year to year. Furthermore, longer trends in weather patterns (e.g., climate change) may cause changes to historical weather patterns. Basing the analysis on a longer time series of observations might increase the "representativeness" of the base weather conditions at least from a historical perspective. However, increasing the reliability of forecast future conditions would require much more elaborate and intensive meteorological forecasting far beyond the scope of this study.

More specifically, the processes of pollutant transport, dispersion and transformation in the atmosphere are complex, meaning that air quality models tend to have fairly high levels of uncertainty. Some key sources of uncertainties are:

(i) uncertainties in the meteorological component arising from the limited spatial resolution of meteorological stations and the need to interpolate meteorological conditions over large areas;
(ii) uncertainties in derived meteorological parameters (such as boundary layer depth and atmospheric stability parameters), which are not measured directly but estimated from other observed parameters;
(iii) uncertainties in hourly emissions profiles and stack parameters for the modelled sources;
(iv) inherent uncertainties in the equations used to represent complex physical and chemical atmospheric processes within CALPUFF; and,
(v) uncertainties in the simplified approach to the relationship between NO_X emissions and ozone production.

The meteorological assumptions used in this analysis are expected to affect all scenarios similarly. No likely bias in the overall ambient air quality forecasts is known. These assumptions increase the range of possible values that may actually materialise in the future but not with to respect one scenario or another.

9.1.2 Air Pollutants

The air pollution forecasts only address emissions and/or concentrations of PM, ozone and GHGs. Thermal generating stations, and in particular CFG facilities, are known to emit other pollutants (e.g., mercury, sulphur dioxide, carbon monoxide) which have known or suspected harmful effects on human health and the environment.

A qualitative review of the likely impacts of mercury is included in this analysis but no allowance is made in the net benefit estimates for these impacts. The potential impacts of these other pollutants are not explicitly considered in this analysis.

Emission rates of these other pollutants tend to be highest for CFG facilities. Accordingly, the net benefits of the non-coal scenarios (i.e., Scenarios 2 and 3) are likely underestimated relative to the CFG alternatives by omitting the impacts of these other pollutants.

9.1.3 Capacity Utilisation and Generation Costs

The four scenarios were designed under quite strict assumptions that may not reflect expected future conditions. Specifically, the scenarios were designed only to provide replacement electricity generation for the CFG facilities. The potential for new generation capacity to generate electricity to satisfy other market demands was not included. The result is that the total generation costs for estimated for Scenarios 2 and 3 may be overestimated on a \$/MWh basis. Of course, if the market becomes more competitive, it is also possible that some of the replacement capacity may be left unused leading to higher than estimated generation costs (at least for certain facilities).

No clear bias can be attributed to these restrictive assumptions. Overcoming this gap would require developing market-wide scenarios and analysing the health and environmental damages throughout the provincial electricity generation system. This scope of analysis was not feasible in this study.

9.1.4 Health Effects

This CBA includes the impacts of a limited number of air pollutants on a limited number of human health effects. Adding more pollutants and more categories of health effects (e.g., doctor's office visits) would result in the estimated benefits of the alternatives likely increasing. The increase would likely be greatest for the non-coal alternatives given their lower emissions of air pollutants.

Premature mortality damages capture acute and long-term exposure impacts of air pollution. All of the other health damage estimates capture only short-term, acute damages. Given that the cohort-based risk factors are about seven times those based on short-term time-series studies, the numbers of cases of these other illnesses may be severely underestimated.

Similarly, the impact of long-term exposure on the development of chronic illnesses (e.g., chronic bronchitis) and increased prevalence of certain illnesses in the population (e.g., asthma) are not captured. These health impacts result in the overall sensitivity of the population to air pollution exposure increasing over time.

For this reason, the health damage estimates reported in this study should be viewed as minimum likely damages. This is particularly so for the CFG alternatives given the greater mass of emissions associated with these alternatives.

9.1.5 Environmental Effects

Similar gaps as exist with the health damage estimates exist with the estimates of environmental effects. Environmental effects are underestimated both as a result of not all air pollutants being included and due to some classes of effects not being included (e.g., corrosion and damage to buildings and structure, reduced visibility, terrestrial ecosystem impacts).

For this reason, the environmental damage estimates should be viewed as minimum likely damages. This is particularly so for the CFG alternatives.

9.1.6 Nuclear Generation

The net benefit estimates in this analysis make no allowance for expected health damages associated with nuclear power generation.

This gap will tend to overestimate the net benefit of Scenario 3 (Nuclear/Gas). The potential magnitude of this effect has not been estimated as part of this analysis.

9.2 Recommendations for Further Analysis

The following recommendations arise from this CBA. These recommendations are designed to improve the net benefit estimates which have been developed.

9.2.1 Effects of Nuclear Generation

The estimated net benefit of Scenario 3 (Nuclear/Gas) does not include an allowance for the health and environmental damages associated with nuclear generation. Including these damages would provide a more accurate estimate of the net benefits of this scenario. It is recommended that this modification be made to the estimated net benefit for Scenario 3.

9.2.2 Intermediate Alternatives

The four scenarios analysed in this CBA represent relatively extreme points in the “landscape” of policy options available for replacing CFG facilities. Many intermediate alternatives exist that may prove more attractive than any of the four alternatives included in this analysis.

The scenarios included in this analysis are based solely on coal, gas and nuclear power generation alternatives. Adding renewable energy technologies would increase the scope and applicability of these results for policy decisions.

Exploring the net benefit of a limited range of scenarios involving different combinations of power generation sources is recommended to gain insights into whether alternatives exist that would yield even greater net benefits than the scenarios considered in this analysis.

9.2.3 Impact of Delays

Scenario 3 (Nuclear/Gas) is based on the assumption that adequate replacement nuclear capacity comes online by 2007. Practically, this may not be realistic. It is recommended that some variations of Scenario 3 be tested in which the required additional nuclear capacity comes online later, perhaps even gradually over a period of time. During this phase-in period, the costs and damages of stop-gap electricity generation would need to be added to the net benefit estimate of Scenario 3.

9.2.4 Market-based Impacts

The scenarios analysed in this CBA are based on some simplifying assumptions regarding the dynamics of the provincial electricity market. The possibility of portions of the replacement electricity generation being supplied by many generators, none of which was dedicated strictly to providing replacement supply, was not examined in detail. Exploring the likely response of the provincial electricity market to the closing of the CFG facilities was beyond the scope of this analysis. Nonetheless, the potential exists for a more efficient means to produce the required replacement electricity capacity and generation. It is recommended that this potential be explored at least, qualitatively, to provide an indication of the significance of the market assumptions used in this analysis on the estimated net benefits.

10 SUMMARY OF FINDINGS

This concluding section provides a summary of the findings of this CBA.

10.1 Scenarios Analysed

This CBA has analysed a broad range of electricity generation alternatives for replacing the electricity produced by CFG facilities. While the number of discrete alternatives is essentially infinite, the range of alternatives considered provides a reasonable understanding of the implications of the general policy directions available to the government.

10.2 Financial Cost Estimates

Detailed estimates of capital, operating, maintenance and fuel costs have been prepared for each scenario. These financial costs have been estimated over a 20-year time horizon (i.e., 2007 to 2026). Standard economic principles have been used to derive estimates of the total present value of these costs (expressed in 2004$), annualised cost (expressed as the average 2004$ cost per year) and levelised cost (expressed as the average 2004$/MWh cost).

The present value of the estimated financial costs over the 20-year time horizon varies significantly from a low of $11.1 billion for Scenario 1 (Base Case) to a high of $23.5 billion for Scenario 2 (All Gas). The difference between the least costly scenario (i.e., Scenario 1 – Base Case) and the most costly scenario (i.e., Scenario 2 – All Gas) is estimated to be about $1.1 billion per year on average. The distribution of these costs varies among the scenarios; with the financial costs of Scenarios 1 (Base Case) and 4 (Stringent Controls) being borne solely by Ontario Power Generation. With Scenario 2 (All Gas) and, to a lesser extent, with Scenario 3 (Nuclear/Gas), the costs are spread among a larger pool of generators.

10.3 Air Quality Impacts

Air quality forecasts for particulate matter and ozone have been produced for southern Ontario based on expected emissions of air pollutants from each electricity generation alternative. The expected differences among the scenarios in terms of air quality impacts are small in absolute terms. Closing the existing coal-fired generation facilities will likely improve overall air quality in Ontario, but significant concentrations of air pollutants will remain from other sources. The greatest improvement will generally be realised immediately downwind of the coal-fired generation facilities. Furthermore, building new gas generation facilities closer to urban centres will cause some local degradation of air quality in terms of ozone concentrations. However, determining the health, environmental and economic significance of these air quality impacts requires rigorous analysis as has been done in this CBA.

10.4 Health Damages

Health damages (i.e., expected mortality and morbidity cases attributable to exposure to air pollution) have been estimated for each scenario. An average annual total of about 660 premature deaths, 920 hospital admissions, 1,090 emergency room visits and 331,000 minor illness cases could be avoided by switching from the Base Case (Scenario 1) to Nuclear/Gas (Scenario 3). Even so, emissions associated with Scenario 3 (Nuclear/Gas) are still expected to contribute to a total of 5 premature deaths, 12 hospital admissions, 15 emergency room visits and 2,500 minor illness cases per year.

A monetary estimate of these health damages has been prepared. The average annual damages range from a low of $0.4 billion for Scenario 3 (Nuclear/Gas) to a high of $3.0 billion for Scenario 1 (Base Case). In other words, implementing Scenario 3 would result in an annual average benefit (i.e., avoided health damages) of $2.6 billion.

The numbers of premature deaths estimated in this analysis are considerably higher than numbers reported in other studies for Ontario for comparable changes in air quality. This difference is due to a revised scientific basis for deriving premature mortality risk factors. The premature mortality risk factors used in this analysis have been derived from cohort studies rather than the more common time series studies that have been used extensively in the past. The cohort-based risk factor are more appropriate for this type of public policy analysis and are being used by other government organisations for similar types of health risk assessments.

The monetary health damage estimates are dominated by the value of avoiding the risk of premature mortality. For this reason, considerable attention has been given to using the best available information on the value that Ontarians place on reducing such risks.

10.5 Environmental Damages

In addition to health damages, emissions from electricity generation cause environmental damages. This analysis includes economic damage estimates relating to the soiling of household materials, crop loss and greenhouse gas emissions.

The monetary estimates corresponding to these environmental damages range on an average annual damages basis from a low of $48 million for Scenario 3 (Nuclear/Gas) to a high of $371 million for Scenario 1 (Base Case). In other words, implementing Scenario 3 in 2007 would result in an annual average benefit (i.e., avoided environmental damages) of $323 million.

The estimates of economic damages for environmental effects are dominated by greenhouse gas control costs (or permit purchasing depending on which is less expensive). For example, with Scenario 1 (Base Case), greenhouse gas costs comprise 94% of the total estimated environmental damages.

10.6 Mercury Damages

Mercury is a highly toxic pollutant emitted from CFG facilities. CFG emission sources account for a significant proportion of Ontario's total mercury emissions. However, estimating mercury-related health and environmental damages is much more complex than what is required for PM and ozone. Mercury persists in the environment and bio-accumulates through food chains, making a direct connection between emissions and exposure difficult. Nonetheless, reducing mercury exposure is certain to yield positive health and environmental benefits.

10.7 Total Cost of Generation

The total cost of electricity generation for each scenario has been estimated. The total cost of generation is the sum of the financial costs and the health and environmental damages. This total cost of generation represents the minimum average amount that society must be willing to pay for this electricity for its generation to be worthwhile.

The levelised total cost of generation range from a low with Scenario 3 (Nuclear/Gas) of $72/MWh to a high of $164/MWh with Scenario 1 (Base Case).

10.8 Net Benefits

The net benefits of the three alternatives relative to the base case (i.e., Scenario 1) have been estimated. The net benefit is calculated by taking the difference between the total cost of generation for Scenario 1 (Base Case) and the total cost of generation estimated for each of the other three scenarios.

The present values of the net benefit for each of the three scenarios over the 20-year time horizon are $20 billion for Scenario 2 (All Gas), $28 billion for Scenario 3 (Nuclear/Gas) and $18 billion for Scenario 4 (Stringent Controls). On the basis of estimated net benefit, Scenario 3 is expected to yield the greatest return of all of the four scenarios analysed.

10.9 Range in Net Benefit Estimates

The financial costs and health and environmental damages which have been estimated involve certain assumptions and expectations concerning the accuracy of the information which has been used and how the future will unfold in terms of economic forces. A systematic and detailed examination of the influence of these expectations and assumptions on the estimated net benefits for the scenarios has been conducted. This examination involved using statistical methods and sensitivity analysis.

The net benefit estimate for Scenario 3 (Nuclear/Gas) varied by 50% (i.e., by about ± $1.2 billion in average annual net benefit) when statistical confidence ranges were used to estimate lower and upper bounds.

The sensitivity of the net benefit estimates to key parameters has also been explored. When one parameter was varied at a time, the influence of that parameter on net benefit estimates could be determined. The net benefit estimates are most sensitive to the social discount rate and the economic value people are willing to pay to reduce the risk of premature mortality from air pollution exposure (i.e., value of a statistical life). For example, with the least sensitive parameter (i.e., gas fuel price), varying the parameter value by about 40% resulted in less than a 7% change in the net benefit estimate for Scenario 3 (Gas/Nuclear). On the other hand, varying the value of a statistical life by slightly more than 25% resulted in a change in net benefit of almost 30%. With all of the sensitivity variations analysed, the net benefit of Scenario 3 (Nuclear/Gas) continued to be greater than that estimated for the other scenarios.

A more complicated sensitivity analysis was also performed. With this technique, several parameters were varied simultaneously and in a logically consistent direction. Three combinations of parameters were specified that were intended to result in the extremes in the range of net benefit estimates. Even with the combination most likely to favour the status quo (i.e., continuing to operate the coal-fired generation facilities beyond 2007), Scenario 3 (Nuclear/Gas) yielded a greater net benefit than Scenario 1 (Base Case). Even with the combination favouring the Base Case, Scenario 3 yielded a positive net benefit that was marginally higher than Scenario 4 (Stringent Controls). All of the other combinations produce net benefit estimates greater than the best estimate value for Scenario 3.

On the basis of these analyses, it is concluded that Scenario 3 (Nuclear/Gas) is expected to yield the greatest net benefit of the alternatives analysed under virtually all reasonable conditions. In other words, Scenario 3, in terms of estimated net benefit, consistently ranks above the other alternatives.

10.10 Gaps and Key Assumptions

Not all health and environmental damages have been included in this analysis. As well, the estimation methodologies have some known limitations. A review of these gaps and limitations has been presented. A qualitative assessment of their potential effects on the estimated net benefit of each scenario has been prepared. These gaps and limitations need to be carefully considered when interpreting the results of this analysis.

Overall, none of these gaps or limitations is likely of sufficient magnitude and significance to change radically the ranking of the scenarios based on estimated net benefit.

10.11 Recommendations For Further Analysis

A number of recommendations have been included that are designed to improve the scope and accuracy of the net benefit estimates. These recommendations are summarised following.

- Health and environmental damages associated with nuclear power generation have not been included in the net benefit estimates for Scenario 3 (Nuclear/Gas) and should be included in the future.
- The results of this analysis provide insight into potential intermediate generation alternatives that may be promising to pursue. Extending this analysis to examine promising intermediate alternatives (e.g., different proportions of nuclear, gas, coal and renewables) would provide useful information for making policy decisions.
- The effects of delays in bringing new capacity on line need to be examined, particularly for Scenario 3 (Nuclear/Gas) since it involves bringing new gas and refurbished nuclear generation capacity on line within a tight timeframe.
- This analysis has been more or less isolated from the dynamics of the electricity market. Further analysis of the scenarios using varying market assumptions, particularly with regards to the likely reaction of the market to a reduction in generation capacity following closure of the coal-fired generation facilities.

10.12 Overall Conclusion

The results of this analysis suggest that Scenario 3 (Nuclear/Gas) is likely to yield the greatest net benefit of the four scenarios analysed. This conclusion is insensitive to the values assigned to a number of the key parameters. While the net benefit estimates in this report are not comprehensive, the results do provide insight into the expected relative performance of the scenarios. This insight is suitable to assist with making policy decisions concerning future electricity generation options for the province.

The results of this CBA are relevant to current initiatives by the provincial government. The government is actively pursuing a diverse range of generation technologies including refurbishing nuclear plants, expanding renewable generation capacity and seeking contracts to import hydroelectric generation from other provinces. The current Clean Energy Sources Request for Proposals could result in 2,500 MW of natural gas-fired generation. There is 3,000 MW of idle nuclear capacity in Ontario. Pickering A Unit 1 (500 MW) is currently being refurbished by OPG and is projected to be in-service by September / October 2005. A decision on refurbishing the remaining two units (500 MW each) will be made shortly. The Government has appointed a special negotiator to arrive at an agreement with Bruce Power to refurbish the two idle units at the Bruce nuclear station (770 MW each). In addition, the government has established an electricity conservation target of 1,350 MW by 2007 and a renewable energy generation target of 1,350 MW by 2010.

A key recommendation of this study is that the range of scenarios analysed should be expanded. Given these initiatives by the government, the scenarios considered in this study represent a subset of the choices available. The methodology and much of the data used in this analysis are applicable for examining the net benefits of other electricity generation alternatives for the province.

LITERATURE CITED

Abt Associates Inc with Computer Sciences Corporation and E.H. Pechan Associates, Inc. 2004. Power Plant Emissions: Particulate Matter-Related Health Damages and the Benefits of Alternative Emission Reduction Scenarios. Prepared for Clean Air Task Force, Boston, ME.

Abt Associates Inc. 2003. US Version BenMAP: Environmental Benefits Mapping and Analysis Program. Users Manual. Prepared for Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, NC. http://www.abtassociates.com

Abt Associates Inc. 2002. Particulate-related health impacts of emissions in 2001 from 41 major US power plants. Prepared for Environmental Integrity Project, Rockefeller Family Fund. Washington, DC. 59pp.

Air Pollution and Health: A European Information System (Apheis). 2004. Health Impact Assessment of Air Pollution and Communication Strategy, Third Year Report 2002-2003. http://www.apheis.net/Apheis3NEW1.pdf

American Thoracic Society. 1985. Evaluation of impairment/disability secondary to respiratory disease. J Med Assoc Ga Sep 74(9):649-54.

Anderson HR, Atkinson RW, Peacock JL, Marston L and K. Konstantinou. 2004. Meta-analysis of time-series studies and panel studies of particulate matter (PM) and ozone. Report of a WHO Task Group, World Health Organization. http://www.euro.who.int/document/e82792.pdf

Atkinson RW, Bremner SA, Anderson SA, Strachan DP, Bland JM and A Ponce de Leon. 1999. Short-term associations between emergency hospital admissions for respiratory and cardiovascular disease and outdoor air pollution in London. Arch. Environ. Health 54: 398-411.

Bloyd C et al. 1996. Tracking and Analysis Framework (TAF) Model Documentation and Users Guide. Argonne National Laboratory, ANL/DIS/TM-36, December. http://www.lumina.com/taf/taflist/dltaf/TAF.pdf

Bourassa Yves. 2005. Personal Communication. Policy Manager, Environmental Economics Environment Canada, 10 Wellington Street, 24th floor, Gatineau, Quebec Canada, K1A 0H3 (819 - 953 - 7651).

Burnett RT, Duwanji A, Dominici F, Goldberg M, Cohen A and D Krewski. 2003. On the relationship between time-series studies, dynamic population studies and estimating loss of life to short-term exposure to environmental risks. Env Health Persp 111(9):1170-1174.

Canadian Council of Ministers of the Environment (CCME). 2001. Canada-Wide Standards for Particulate Matter PM and Ozone. 64 pp. http://www.ccme.ca

California Air Resources Board (CARB). 2005. Air Resources Board Staff Report Public Hearing to consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates. Prepared by the Staff of the Air Resources Board and the Office of Environmental Health Hazard Assessment. May 3, 2002. California Environmental Protection Agency. ftp://ftp.arb.ca.gov/carbis/regact/aaqspm/isor.pdf

California Air Resources Board (CARB). 2004. Review of the California Ambient Air Quality Standard for Ozone, Volume I Public Review Draft June 21, 2004. California Environmental Protection Agency. http://www.arb.ca.gov/research/aaqs/ozone-rs/ozone-draft-rpt.htm

Canadian Institute for Health Information (CIHI). 2002. National and Provincial Hospital Admissions (00/01) by ICD code and age grouping. Hospital Morbidity Database 2000-01 Tabular Report.

Center for Disease Control and Prevention (CDC). 2001. Report: Exposure to Environmental Chemicals.

Clear the Air. 2005. Pollution on the Rise-Local Trends in power Plant Pollution. Prepared by US PIRG Education Fund. Washington, D.C. http://www.cleartheair.org/reports/pollution_on_the_rise.pdf

Dockerty DW, Pope III CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG and F E Speizer. 1993. An association between air pollution and mortality in six US cities. N Engl J Med 329(24):1753-1759.

DSS Management Consultants Inc. 2000. Refinements and Updating: Illness Costs of Air Pollution. Report prepared for the Ontario Medical Assoc (OMA).

ExternE. 2003. External Costs Research Results on Socio-Environmental Damages due to Electricity and Transport. Brussels: European Commission. http://www.europa.eu.int/comm/research/rtdinfo_en.html

ExternE. 1999. Externalities of Energy, Volume 7: Methodology 1998. Update. Brussels: European Commission. http://www.externe.info/reportex/vol7.pdf

Grandjean P., Weihe P., White R.F., Debes F., Araki S., Yokoyama K., Murata, K., Sorensen, N. Dahl, R. and Jorgensen, P.J. 1997. Cognitive deficit in 7-year-old children with prenatal exposure to methylmercury. Neurotoxicology and Teratology. 20(1): 1-12.

Hagen DA, Vincent JW and PG Welle. 1999. Economic Benefits of Reducing Mercury Deposition in Minnesota. Prepared for the Minnesota Pollution Control Agency. http://www.pca.state.mn.us/publications/reports/mercury-economicbenefits.pdf

Heagle HS, Kerss LW, Temple PJ, Kohut RJ, Miller JE and H.E. Heggestad. 1988. Factors influencing ozone dose-yield response relationships in open-top field chamber studies. *In* Assessment of Crop Loss Yield from Air Pollutants. Heck WW, OC Taylor OC, and DT Tingey (eds.). Elsevier Applied Science: London. pp. 141-179.

Health Effects Institute (HEI). 2003. Revised Analyses of Time Series Study of Air Pollution and Health Special Report: Revised Analyses of the National Morbidity, Mortality and Air Pollution Study, Part II *and* Revised Analyses of Selected Time-Series Studies. Health Effects Institute, Cambridge, ME

Holland, M. and Watkiss, P. nd, BeTa: Benefits Table database: Estimates of the marginal external costs of air pollution in Europe: Version E1.02a. Prepared for European Commission DG Environment. http://europa.eu.int/comm/environment/enveco/air/betaec02aforprinting.pdf

Indian and Northern Affairs Canada (INAC). 2004. Fact Sheet: English-Wabigoon River Mercury Compensation. http://www.ainc-inac.gc.ca/pr/info/ewr_e.html

Ito K. 2003. Associations of particulate matter components with daily mortality and morbidity in Detroit, Michigan. *In* Revised Analyses of Time-series Studies of Air Pollution and Health. Special Report. Boston, MA: Health Effects Institute. pp.143-156. http://www.healtheffects.org/news.htm

Jakus P, Krupnick A and A Jakus. 2002. The Benefits and Costs of Fish Consumption Advisories for Mercury. Discussion Paper 02–55. Washington: Resources for the Future http://www.rff.org/rff/Documents/RFF-DP-02-55.pdf

Krewski D, Burnett RT, Goldberg M, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M and W H White. 2000. Reanalysis of the Harvard Six Cities Study and the American Cancer Society Study for Particulate Air Pollution and Mortality: Investigator's Report. A Special Report of the Institute's Particle Epidemiology Reanalysis Project. Health Effects Institute, Cambridge, ME.

Krupnick A. 2004. Valuing Health Outcomes: Policy Choices and Technical Issues. Washington: Resources for the Future. http://www.rff.org/rff/Documents/RFF-RPT-ValuingHealthOutcomes.pdf

Krupnick A, Alberini A, Cropper M, Simon N, O'Brien B, Goeree R and M Heintzelman. 2002. Age, health, and the willingness to pay for mortality risk reductions: A contingent valuation survey of Ontario residents**.** J Risk Uncert 24:161-186

Loomis DP, Castillejos M, Gold DR, McDonnell W, and VH Borja-Aburto. 1999. Air pollution and infant mortality in Mexico City. Epidemiol 10(2):118-23.

Lourie, B. 2001. Science Policy Interface: Setting Mercury Control Standards for Coal Power Plants. Paper presented at International Conference on Mercury as a Global Pollutant, Minamata, Japan

Manuel E Jr, Horst RL Jr, Brennan K, Lanen W, Duff MC and JK Tapiero. 1982. Benefits analysis of alternative secondary national ambient air quality standards for sulfur dioxide and total suspended particulates, Volume II. Prepared by USA Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC.

McClelland G, Schulze W, Waldman D, Irwin J, Schenk JD, Stewart T, Deck L and M Thayer. 1991. Valuing eastern visibility: A test of the contingent valuation method. Report to the USA Environmental Protection Agency.

National Academy of Sciences. 2002. Toxicological Effects of Methylmercury. National Research Council. National Academy Press, Washington, DC.

National Pollutant Release Inventory (NPRI). 2004. 2002 Data Set Accessed March 1, 2005

Pearce D. 2003. The social cost of carbon and its policy implications. Oxf Rev Econ Policy 19(3):362-384.

Pope III CA, Burnett RT, Thun WJ, Calle E, Krewski D, Kazuhiko I and G. D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287(9):1132-1141.

Pope IIICA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE and C.W. Heath, Jr. 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med 151:669-674.

Schwartz J, Zanobetti A and T. Bateson. 2003. Morbidity and Mortality among Elderly Residents of Cities with Daily PM Measurements *In* Revised Analyses of Time-Series Study of Air Pollution and Health: Revised Analyses of National Morbidity, Mortality and Air Pollution Study (NMMAPS), Part II. Health Effects Institute, Cambridge, MA pp.25-58.

Schwartz J, Laden F and A Zanobetti. 2002. The Concentrations-response relationship between PM2.5 and daily deaths. Env Health Persp 110(10):1025-1030.

Scire JS, Robe FR, Ferneau ME, and RJ Yamartino. 2000. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Technologies Inc., Jan. 2000, 332 pp.

Scire JS, Strimaitis DG and R.J. Yamartino, 1999. A User's Guide for the CALPUFF Model (Version 5.01). Earth Technologies Inc., Jan. 2000, 521 pp.

Spiro P. 2004. The Social Discount Rate for Ontario Government Investment Projects. Macroeconomic Analysis and Policy Branch, Office of Economic Policy, Ontario Ministry of Finance.

Statistics Canada. 2005. CANSIM II SERIES V122518. Ottawa, Statistics Canada.

Stieb DM, De Civita P, Johnson R, Manary MP, Anis AH, Beveridge RC and S Judek. 2002. Economic evaluation of the benefits of reducing acute cardiorespiratory morbidity associated with air pollution. Env Health: A Global Science Access Source (1):1-13.

Stieb D, Burnett RT, Beveridge RC and JR Brook. 1996. Association between ozone and asthma emergency department visits in Saint John, New Brunswick, Canada. Env Health Perspect 104(12):1354-1360.

Stieb DM, Pengelly LD, Arron N, Taylor SM and ME Raizenne. 1995. Health effects of air pollution in Canada: Expert panel findings for the Canadian Smog Advisory Program. Can Respir J 2(3):155-160.

Stratus Consulting. 1999. Air Quality Valuation Model (AQVM) Version 3.0. Report 2: Methodology. Prepared for Environment Canada..

Sumaila U.R and C Walters. 2005. Intergenerational discounting: a new intuitive approach. Ecol Econ 52(2):135-142.

Thurston GD and K Ito. 2001. Epidemiological studies of acute ozone exposures and mortality. J Expo Anal Environ Epidemiol 11:286-94.

Tolbert P et al. 2000. Air quality and pediatric emergency room visits for asthma in Atlanta, Georgia. Am. J Epidemiol 151:798-810.

United Nations Environment Program (UNEP). 2003. Global Mercury Assessment. Chemicals Group. Geneva, Switzerland.

US Environmental Protection Agency (EPA). 2005. Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical information OAQPS Staff Paper, Second draft, January, 2005. Office of Air Quality Planning and Standards, Research Triangle Park, NC, EPA-452/D-05-001. http://www.epa.gov/ttn/naaqs/standards/pm/data/pm_staff_paper_2nddraft.pdf

US Environmental Protection Agency (EPA), 2004. Advisory on Plans for Health Effects Analysis in the Analytical Plan for EPA's Second Prospective Analysis - Benefits and Costs of the Clean Air Act, 1990-2020 Advisory by the Health Effects Subcommittee of the Advisory Council on Clean Air Compliance Analysis. Washington, D.C. Report No.: EPA-SAB-COUNCIL-ADV-04-002 Environmental. http://www.epa.gov/sab/pdf/council_adv_04002.pdf

US Environmental Protection Agency (EPA). 2003a. Appendix W of 40 CFR Part 51 - Guideline on Air Quality Models.

US Environmental Protection Agency (EPA). 2003b. Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical information OAQPS Staff Paper, December draft.

US Environmental Protection Agency (EPA). 2003c. America's Children and the Environment: Measures of Contaminants, Body Burdens, and Illnesses

US Environmental Protection Agency (EPA). 1997. Mercury Study Report to Congress

Vedal S, Petkau J, White R and J Blair, 1998. Acute effects of ambient inhalable particles in asthmatic and nonasthmatic children. Am J Respir Crit Care Med 157:1034-1043.

Watson W and J Jaksch. 1982. Air pollution: Household soiling and consumer welfare losses. J Env Econ Man 9:248-262.

World Health Organization (WHO). 2003. Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. Report on a WHO Working Group. Bonn, Germany.

World Health Organization (WHO). 2000. Air Quality Guidelines for Europe, 2nd edn. WHO Regional Publications, European Series No 91. Copenhagen.

Wu, B. 2003. Lethal Legacy: A Comprehensive Look at America's Dirtiest Power Stations. U.S. Public Interest Research Group (US PIRG) Education Fund Report. Prepared for Clear the Air, the National Campaign against Dirty Power.

A APPENDIX A – AIR POLLUTION MODELLING

A.1 Purpose and Scope

The purpose of the air pollution modelling is to assess the impacts on ambient air quality of pollution emissions from alternative means of generating the electricity expected to be produced by Ontario's coal-fired generating (CFG) stations in the future. The air quality impacts of the following four generation alternatives were analysed (See Scenario Descriptions for a complete description of each):

- Scenario 1 – Base Case
- Scenario 2 – All Gas
- Scenario 3 – Nuclear and Gas
- Scenario 4 – Stringent Controls.

Air quality modelling was used to produce a reasonable estimation of the quantitative effects of the air pollutant emissions associated with each scenario on annual or seasonally averaged air quality (specifically for O_3 and PM_{10}), for each census division in southern Ontario.

The northern parts of Ontario and the two northern CFG facilities (i.e., Atikokan and Thunder Bay) were not included in the air quality modelling. These CFG facilities emit a small fraction of the total provincial CFG emissions (i.e., >5%) and are outside the main airshed in which southern Ontario CFG emissions interact. For these reasons, the scope of the air quality modelling was limited to southern Ontario.

The emission scenarios are representative of the long-term average emissions and meteorological conditions that can be expected in the area. Generalizations and assumptions were made that are designed to produce forecasts that will best reflect these long term conditions. Invariably, short-term variations in actual air quality conditions will occur but over the long term, forecast air quality conditions are expected to approximate long-term average conditions.

The emission scenarios are designed to address only the replacement of the generating capacity and electricity generation of the Lambton and Nanticoke CFG stations. The scenarios do not account for likely changes in the overall provincial electricity market in the year 2007 or beyond, nor do they account for the electricity deficit caused by the shutdown of the Lakeview CFG station in Mississauga in 2005.

A.2 Air Pollutant Emissions Profiles

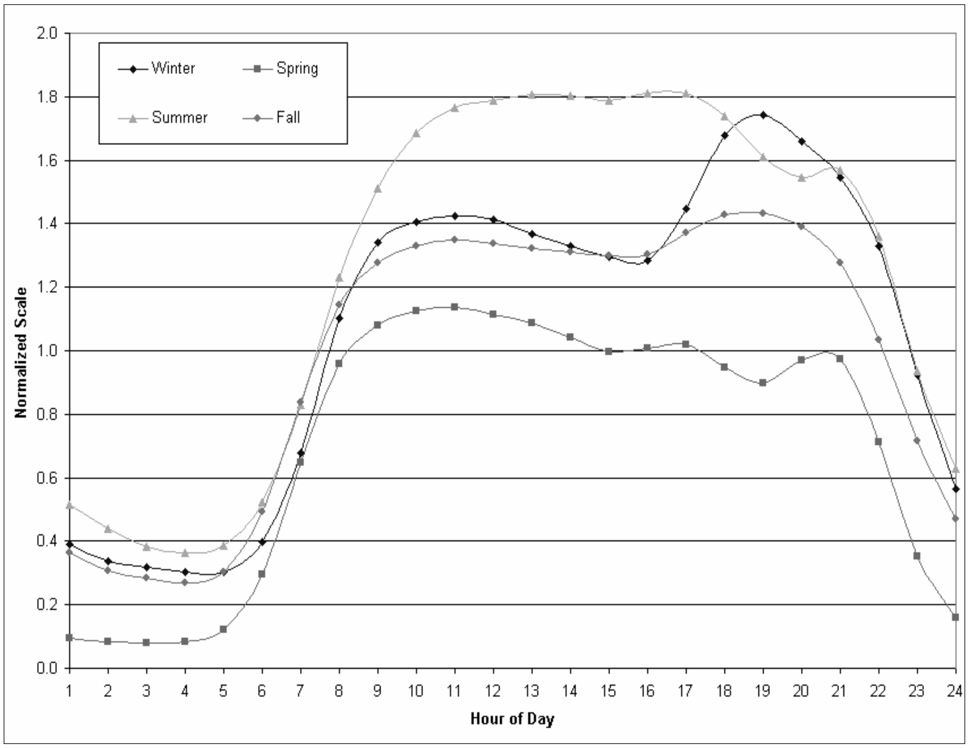
The impact of power plant emissions on air quality depends upon the level of the pollutant emissions, meteorological conditions and air pollution chemistry. For this study, information on forecasted annual emissions of particulate matter (less than or equal to 10 microns, PM_{10}), sulphur dioxide (SO_2) and oxides of nitrogen (NO_X) for each of the power generation scenarios was developed in consultation with the operators of the facilities (i.e., OPG) and the Ontario Ministry of Energy. These data were reviewed and discussed in detail with OPG and Ontario Ministry of Energy staff to arrive at representative emissions and stack parameters for each of the scenarios modelled. Realistic hour-of-day by season-of-year temporal emission profiles were developed for this study based on representative (i.e., typical) hourly load information provide by OPG.

Tables A-1 through A-4 provide detailed information on the emission and stack parameters used in this study. Specific assumptions are provided in the footnotes under each table.

In practice, generation units do not operate continuously at the Maximum Continuous Rating. Instead, actual generation fluctuates up and down depending on electricity demand. Stack flow rates and exhaust temperatures fluctuate up and down correspondingly, as will the number of units operating at any point in time. In the absence of information on hourly variations for any of the scenarios modelled, constant values were assumed, based on an estimate of "average operating conditions".

Average hour-of-day and season-of-year emission profiles were derived from representative hourly power production data. Figure A-1 illustrates the dimensionless hourly temporal profiles used to allocate annual emissions by hour of day and by season of year within the air quality model.

Figure A.1 Temporal Profiles for Proportioning of Daily Emissions



A.3 Air Quality Modelling

The air quality modelling involved two steps. The first step is the modelling of meteorological conditions. These conditions affect the dispersion of pollutants. The second step is to track pollutant concentrations and chemical reactions in the atmosphere. Two separate models were used for these purposes.

A.3.1 CALMET

Meteorological modelling was performed using CALMET, which, in combination with surface and upper air meteorological data and geophysical parameters, generates 3-dimensional meteorological fields. A relatively coarse resolution of 20 km spacing was used for southern Ontario.

Table A-1 Scenario 1 (Base Case) Emissions Parameters

Facility [1]	OPG Lambton				OPG Nanticoke							
Unit/Flue [2]	1	2	3	4	1	2	3	4	5	6	7	8
Rated Power Output (MW)	485	485	498	498	490	490	490	490	490	490	490	490
Fraction of Total Available Power [3]	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Unit Generation (TWh/yr) [4]	1	1	3.25	3.25	1.925	1.925	1.925	1.925	2.45	2.45	2.75	2.75
Annual Generation (TWh/yr)	2		6.5		7.7				4.9		5.5	
Annual Utilization (ACF) [5]	24%		74%		45%				57%		64%	
Stack [2]	Stack 1		Stack 2		Stack 1				Stack 2			
Emission Controls [6]	LNB, ESP	LNB, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	LNB, ESP	LNB, ESP	LNB, ESP	LNB, ESP	LNB, OFA, ESP	LNB, ESP	LNB, SCR, ESP	LNB, SCR, ESP
NOx as NO (g/kWh) [7]	1.1	1.1	0.3	0.3	1.2	1.2	1.2	1.2	1.05	1.2	0.3	0.3
NOx as NO (Mg/yr)	1100	1100	975	975	2310	2310	2310	2310	2572.5	2940	825	825
NOx as NO (Mg/yr)	2200		1950		9240				7163			
SO2 (g/kWh)	5.28	5.28	0.938	0.938	3.65	3.65	3.65	3.65	3.65	3.65	3.65	3.65
SO2 (Mg/yr)	5280	5280	3048.5	3048.5	7026.25	7026.25	7026.25	7026.25	8942.5	8942.5	10037.5	10037.5
SO2 (Mg/yr)	10560		6097		28105				37960			
PM10 (g/kWh)	0.19	0.19	0.01	0.01	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
PM10 (Mg/yr)	190	190	32.5	32.5	365.75	365.75	365.75	365.75	465.5	465.5	522.5	522.5
PM10 (Mg/yr)	380		65		1463				1976			
UTM East (km)	379.818	379.818	379.906	379.906	577.69	577.69	577.69	577.69	577.428	577.428	577.428	577.428
UTM North (km)	4739.152	4739.152	4739.008	4739.008	4738.782	4738.782	4738.782	4738.782	4738.703	4738.703	4738.703	4738.703
Flue exit height above grade (m)	169.8	169.8	168.0	168.0	198.1	198.1	198.1	198.1	198.1	198.1	198.1	198.1
Flue exit diameter (m)	7.49	7.49	5.00	5.00	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49
Flue exit flow rate (m^3/s) [8]	855	855	630	630	844	844	844	844	844	844	844	844
Flue exit velocity (m/s) [8]	19.40	19.40	32.10	32.10	35.67	35.67	35.67	35.67	35.67	35.67	35.67	35.67
Flue exit temperature (^oC) [8]	149	149	53	53	133	133	133	133	133	133	133	133

Notes for Table A-1

[1] Modelled scenario generation is based on Lambton and Nanticoke achieving NO_X limit of 17 Gg plus 33% allowance for emission credits.
[2] Each unit is routed to an individual flue in one of two stacks.
[3] Individual fraction of total available power for this scenario
[4] Generation is assumed to be divided evenly among units.
[5] Annual utilization of available capacity is based on proposed annual generation.
[6] SCR - Selective Catalytic Reduction units for controlling NO_X.
FGD - Wet Flue Gas Desulphurization units for controlling SO_2
LNB - Low NO_X Burner for controlling NO_X.
OFA – Over-fired Air for controlling NO_X.
ESP - Electrostatic Precipitator for controlling PM.
[7] NO_X is expressed as NO on a mass basis and therefore does not account for the relatively small mass of NO_2 emitted (≤ 2%).
[8] Flue exhaust parameters are based on Maximum Continuous Rating (MCR).

Table A-2 Scenario 2 (All Gas) Emissions Parameters

Small 2x1 Combined Cycle Facilities [2]

Facility [1]	Filler Plant, Mississauga		Filler Plant, Toronto		Filler Plant, Etobicoke		Filler Plant, Thorold	
Gas Turbine Unit	1	2	1	2	1	2	1	2
Rated Power Output (MW)	125		180		242		273	
Fraction of Total Available Power [3]	1.9%		2.8%		3.8%		4.2%	
Annual Generation (TWh/yr) [4]	0.5		0.7		1.0		1.1	
Annual Utilization (ACF) [5]	47%		47%		47%		47%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB	LNB	LNB	LNB	LNB	LNB	LNB	LNB
NOx as NO (g/kWh) [9]	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
NOx as NO (Mg/yr)	61.20	61.20	88.13	88.13	118.49	118.49	133.66	133.66
NOx as NO (Mg/yr)	122		176		237		267	
SO2 (g/kWh) [10]	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
SO2 (Mg/yr)	0.609	0.609	0.877	0.877	1.179	1.179	1.331	1.331
SO2 (Mg/yr)	1.2		1.8		2.4		2.7	
PM10 (g/kWh) [11]	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
PM10 (Mg/yr)	9.75	9.75	14.03	14.03	18.87	18.87	21.29	21.29
PM10 (Mg/yr)	19		28		38		43	
UTM East (km)	607.215	607.215	634.841	634.841	617.046	617.046	646.485	646.485
UTM North (km)	4837.992	4837.992	4835.003	4835.003	4825.336	4825.336	4773.181	4773.181
Flue exit height above grade (m)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Flue exit diameter (m) [12]	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Flue exit flow rate (m^3/s) [12]	307	307	307	307	307	307	307	307
Flue exit velocity (m/s) [12]	13.0	13.00	13.0	13.00	13.0	13.00	13.0	13.00
Flue exit temperature (^oC) [12]	100	100	100	100	100	100	100	100

Medium 2x1 Combined Cycle Facilities [2]

Facility [1]	OPG Filler Plant, Nanticoke		OPG Filler Plant, Lambton		OPG Filler Plant, Hamilton	
Gas Turbine Unit	1	2	1	2	1	2
Rated Power Output (MW)	538		455		455	
Fraction of Total Available Power [3]	8.3%		7.1%		7.1%	
Annual Generation (TWh/yr) [4]	2.2		1.9		1.9	
Annual Utilization (ACF) [5]	47%		47%		47%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB	LNB	LNB	LNB	LNB	LNB
NOx as NO (g/kWh) [9]	0.086	0.09	0.086	0.09	0.086	0.09
NOx as NO (Mg/yr)	95.44	95.44	80.72	80.72	80.72	80.72
NOx as NO (Mg/yr)	191		161		161	
SO2 (g/kWh) [10]	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022
SO2 (Mg/yr)	2.428	2.428	2.053	2.053	2.053	2.053
SO2 (Mg/yr)	4.9		4.1		4.1	
PM10 (g/kWh) [11]	0.035	0.035	0.035	0.035	0.035	0.035
PM10 (Mg/yr)	38.84	38.84	32.85	32.85	32.85	32.85
PM10 (Mg/yr)	78		66		66	
UTM East (km)	577.687	577.687	379.818	379.818	595.273	595.273
UTM North (km)	4738.788	4738.788	4739.153	4739.153	4790.757	4790.757
Flue exit height above grade (m)	45.7	45.7	45.7	45.7	45.7	45.7
Flue exit diameter (m) [12]	5.8	5.8	5.8	5.8	5.8	5.8
Flue exit flow rate (m^3/s) [12]	519	519	519	519	519	519
Flue exit velocity (m/s) [12]	19.7	19.70	19.7	19.70	19.7	19.70
Flue exit temperature (^oC) [12]	100	100	100	100	100	100

Table A.2 Scenario 2 (All Gas) Emissions Parameters (*continued*)

Large 2x1 Combined Cycle Facilities [2]

Facility [1]	OPG Filler Plant, Nanticoke		OPG Filler Plant, Lambton		Filler Plant, Brampton		Filler Plant, Lakeview	
Gas Turbine Unit	1	2	1	2	1	2	1	2
Rated Power Output (MW)	1000		1047		932		1200	
Fraction of Total Available Power [3]	15.5%		16.2%		14.5%		18.6%	
Annual Generation (TWh/yr) [4]	4.1		4.3		3.8		5.0	
Annual Utilization (ACF) [5]	47%		47%		47%		47%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB, SCR	LNB, SCR	LNB, SCR	LNB, SCR	LNB, SCR	LNB, SCR	LNB, SCR	LNB, SCR
NOx as NO (g/kWh) [9]	0.033	0.03	0.033	0.03	0.033	0.03	0.033	0.03
NOx as NO (Mg/yr)	68.99	68.99	72.23	72.23	64.30	64.30	82.78	82.78
NOx as NO (Mg/yr)	138		144		129		166	
SO2 (g/kWh) [10]	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022	0.0022
SO2 (Mg/yr)	4.513	4.513	4.725	4.725	4.206	4.206	5.415	5.415
SO2 (Mg/yr)	9.0		9.4		8.4		10.8	
PM10 (g/kWh) [11]	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
PM10 (Mg/yr)	61.04	61.04	63.91	63.91	56.89	56.89	73.24	73.24
PM10 (Mg/yr)	122		128		114		146	
UTM East (km)	577.687	577.687	379.818	379.818	606.806	606.806	617.046	617.046
UTM North (km)	4738.788	4738.788	4739.153	4739.153	4844.384	4844.384	4825.336	4825.336
Flue exit height above grade (m)	61	61	61	61	61	61	61	61
Flue exit diameter (m) [12]	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Flue exit flow rate (m^3/s) [12]	708	708	708	708	708	708	708	708
Flue exit velocity (m/s) [12]	24.3	24.30	24.3	24.30	24.3	24.30	24.3	24.30
Flue exit temperature (^{o}C) [12]	100	100	100	100	100	100	100	100

Table A-2

[1] Plants assumed to operate in combined cycle mode in a 2 x 1 configuration (2 combustion turbines (CT) and one steam turbine (ST)) at a minimum, with each CT venting through a heat recovery steam generator (HRSG) with its own stack (i.e., 2 stacks per plant).

[2] Plants divided into three size classes by generation size: small, <300 MW; medium, 300-700 MW; large, >700 MW. Size classes based on generation achieved by combined cycle plants in a 2 x 1 configuration using standard combustion turbine sizes (GE turbines). Steam turbine assumed to have similar generation as a single CT based on experience with typical 2 x 1 combined cycle plant designs.

[3] Individual fraction of total available power for this scenario.

[4] Generation amount assumes replacement dispatching is distributed evenly over all proposed combined-cycle gas-fired plants. It is calculated based on the fraction of total replaced MW (scale factor) and total coal-fired generation being replaced (26.6 TWh).

[5] Annual utilization of available capacity based on proposed annual generation.

[6] Emissions derived from overall plant data (accounting for efficiency on an HHV basis), representing overall plant-wide emissions (from 2 CT's) and accounting for electrical production by a steam turbine (i.e., emissions on a MW generation basis pro-rated to include steam turbine contribution). Values do not include duct burner emissions; assumed to be from CT's only. Large plants assume post-combustion NOx controls (e.g., SCR, SCO NO_X, etc.). Large plants also include an allowance for NH_3 slip due to SCR use. Small and medium classes have no post-combustion controls, and achieve NO_X reduction through burner configuration (low-NO_X or ultra low- NO_X). Conversions based on U.S. EPA 40CFR60 F-factors to convert PPM NOx to lbs NOx/MMBTU.

[7] Facility's NO_X emissions are increased by 20% for large and medium facilities, and by 15% for small facilities, to account for higher emissions during heat rate and load variations. PM and SO_2 emissions are linked to fuel consumption and hence do not experience the same increases due to cycling / peaking.

[8] LNB - Low NO_X Burner for controlling NO_X.

[9] NO_X as NO. Large power plants are assumed to use post-combustion controls (SCR, SCO NO_X, etc.) to achieve reduced NO_X emissions; NO_X emissions derived from typical permitted levels in Ontario and US for SCR control (~3.5 ppmvd @15% O_2). Small plants are based on typical low-NO_X burners (25 ppm @15% O_2) and medium plants on ultra low- NO_X burners (9 ppm @15% O_2) from manufacturer (GE) data. Cycling is assumed to increase overall NO_X emissions by about 20% for large and medium units (heat rate and low load variations) and about 15% for small units (cycling duty). Conversions based on U.S EPA 40CFR60 F-factors to convert PPM NO_X to lbs NO_X /MMBTU, and adjusted for NO molecular weight.

[10] Based on 100% conversion of typical fuel sulphur from Ontario gas supply data at 0.24 grains S/100 scf (5.5 mg S/m3) with gas HHV of 1000 BTU/ft3 (~900 BTU/ft3 LHV). Emission factor equivalence of 0.0007 lb/MMBTU.

[11] All particulate from gas turbines is on the order of 1 micron, hence all PM is assumed to be $PM_{2.5}$ (= PM_{10}). Particulate is the total of the filterable, condensable and secondary (in-stack sulphate) fractions. Filterable PM is based on manufacturer's (GE/MHI) guarantee for typical turbines in each size class (5 lb/hr or 0.0055 lb/MMBTU for small; 9 lb/hr or 0.0055 lb/MMBTU for mid; 12 lb/hr or 0.0043 lb/MMBTU for large). Condensable PM is assumed equal to filterable particulate based on manufacturer's (GE) estimates and experience with similar projects in Ontario and California. Sulphate PM (0.0007 lb/MMBTU) represents secondary particulate formed as a result of reactions with NH_3 in the SCR (assumes all SO_4 reacts to form PM) and hence is only found in large class plants.

[12] Stack parameters are based on manufacturer's (GE/MHI) data for typical small and large 2 x 1 combined cycle plant designs with each turbine venting through an HRSG. Medium plant stack parameters are assumed to be median of small and large class parameters.

[13] Temperature based on HSRG's extracting bulk of exhaust heat (T decrease from ~1100°F to 212°F). Exhaust temperature based on those achieved in similar 2x1 combined cycle plant designs in Ontario and US.

Table A-3 Scenario 3 (Nuclear/Gas) Emissions Parameters

Small 2x1 Combined Cycle Facilities [2]

Facility [1]	Filler Plant, Mississauga		Filler Plant, Toronto		Filler Plant, Thorold	
Gas Turbine Unit	1	2	1	2	1	2
Rated Power Output (MW)	125		180		273	
Fraction of Total Available Power [3]	9.0%		13.0%		19.7%	
Annual Generation (TWh/yr) [4]	0.7		1.0		1.5	
Annual Utilization (ACF) [5]	63%		63%		63%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB	LNB	LNB	LNB	LNB	LNB
NOx as NO (g/kWh) [9]	0.24	0.24	0.24	0.24	0.24	0.24
NOx as NO (Mg/yr)	81.45	81.45	117.29	117.29	177.90	177.90
NOx as NO (Mg/yr)	163		235		356	
SO2 (g/kWh) [10]	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
SO2 (Mg/yr)	0.811	0.811	1.168	1.168	1.771	1.771
SO2 (Mg/yr)	1.6		2.3		3.5	
PM10 (g/kWh) [11]	0.038	0.038	0.038	0.038	0.038	0.038
PM10 (Mg/yr)	12.97	12.97	18.68	18.68	28.33	28.33
PM10 (Mg/yr)	26		37		57	
UTM East (km)	607.215	607.215	634.841	634.841	646.485	646.485
UTM North (km)	4837.992	4837.992	4835.003	4835.003	4773.181	4773.181
Flue exit height above grade (m)	30.5	30.5	30.5	30.5	30.5	30.5
Flue exit diameter (m) [12]	5.5	5.5	5.5	5.5	5.5	5.5
Flue exit flow rate (m^3/s) [12]	307	307	307	307	307	307
Flue exit velocity (m/s) [12]	13.0	13.00	13.0	13.00	13.0	13.00
Flue exit temperature (^{o}C) [12]	100	100	100	100	100	100

Medium 2x1 Combined Cycle Facilities [2]

Facility [1]	OPG Filler Plant, Nanticoke		OPG Filler Plant, Lambton	
Gas Turbine Unit	1	2	1	2
Rated Power Output (MW)	351		455	
Fraction of Total Available Power [3]	25.4%		32.9%	
Annual Generation (TWh/yr) [4]	1.9		2.5	
Annual Utilization (ACF) [5]	63%		63%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB	LNB	LNB	LNB
NOx as NO (g/kWh) [9]	0.086	0.09	0.086	0.09
NOx as NO (Mg/yr)	82.87	82.87	107.43	107.43
NOx as NO (Mg/yr)	166		215	
SO2 (g/kWh) [10]	0.0022	0.0022	0.0022	0.0022
SO2 (Mg/yr)	2.108	2.108	2.733	2.733
SO2 (Mg/yr)	4.2		5.5	
PM10 (g/kWh) [11]	0.035	0.035	0.035	0.035
PM10 (Mg/yr)	33.73	33.73	43.72	43.72
PM10 (Mg/yr)	67		87	
UTM East (km)	577.687	577.687	379.818	379.818
UTM North (km)	4738.788	4738.788	4739.153	4739.153
Flue exit height above grade (m)	45.7	45.7	45.7	45.7
Flue exit diameter (m) [12]	5.8	5.8	5.8	5.8
Flue exit flow rate (m^3/s) [12]	519	519	519	519
Flue exit velocity (m/s) [12]	19.7	19.70	19.7	19.70
Flue exit temperature (^{o}C) [12]	100	100	100	100

Table A.3 Scenario 3 (Nuclear/Gas) Emissions Parameters (*continued*)

Peaking Simple Cycle Facilities [2]

Facility [1]	OPG Peaker Plant, Lambton		OPG Peaker Plant, Nanticoke		Filler Peaker Plant, Oakville		Filler Peaker Plant, Brampton		OPG Peaker Plant, Lambton	
Gas Turbine Unit	1	2	1	2	1	2	1	2	1	2
Rated Power Output (MW)	396		396		396		396		396	
Fraction of Total Available Power [3]	20.0%		20.0%		20.0%		20.0%		20.0%	
Annual Generation (TWh/yr) [4]	0.2		0.2		0.2		0.2		0.2	
Annual Utilization (ACF) [5]	6%		6%		6%		6%		6%	
Stack [6,7]	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2	Stack 1	Stack 2
Emission Controls [8]	LNB	LNB	LNB	LNB	LNB	LNB	LNB	LNB	LNB	LNB
NOx as NO (g/kWh) [9]	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
NOx as NO (Mg/yr)	10.61	10.61	10.61	10.61	10.61	10.61	10.61	10.61	10.61	10.61
NOx as NO (Mg/yr)	21		21		21		21		21	
SO2 (g/kWh) [10]	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034	0.0034
SO2 (Mg/yr)	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337	0.337
SO2 (Mg/yr)	0.67		0.67		0.67		0.67		0.67	
PM10 (g/kWh) [11]	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054	0.054
PM10 (Mg/yr)	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
PM10 (Mg/yr)	11		11		11		11		11	
UTM East (km)	379.818	379.818	577.687	577.687	609.897	609.897	606.806	606.806	379.818	379.818
UTM North (km)	4739.153	4739.153	4738.788	4738.788	4816.439	4816.439	4844.384	4844.384	4739.153	4739.153
Flue exit height above grade (m)	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Flue exit diameter (m) [12]	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
Flue exit flow rate (m^3/s) [12]	519	519	519	519	519	519	519	519	519	519
Flue exit velocity (m/s) [12]	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
Flue exit temperature (°C) [12]	538	538	538	538	538	538	538	538	538	538

Notes for Table A-3

[1] Combined cycle plants assumed to operate in a 2 x 1 configuration (2 combustion turbines (CT) and one steam turbine (ST)) at a minimum, with each CT venting through a heat recovery steam generator (HRSG) with its own stack (i.e., 2 stacks per plant). Single cycle plants are configured with 2 GTs and no HRSG or ST..

[2] Combined cycle plants divided into three size classes by generation size: small, <300 MW; medium, 300-700 MW; large, >700 MW. Size classes based on generation achieved by plants in a 2 x 1 configuration using standard combustion turbine sizes (GE turbines). Steam turbine assumed to have similar generation as a single CT based on experience with typical 2 x 1 combined cycle plant designs..

[3] Individual fraction of total available power for this scenario by plant type (i.e., combined cycle vs. single cycle).

[4] The 3 additional nuclear units at Pickering A and Bruce 1,2 assumed to produce 18 TWh/yr to replace coal (a higher theoretical 21-22 TWh/a is limited by nuclear cycling and load curves). Remaining generation amount (8.6 TWh) assumed to be distributed evenly within each gas-fired plant type (combined cycle vs. single cycle). It is calculated based on the fraction of total replaced MW (scale factor) and total coal-fired generation being replaced (7.6 TWh of combined cycle and 1 TWh of single cycle generation)..

[5] Annual utilization of available capacity based on proposed annual generation.

[6] Emissions derived from overall plant data (accounting for efficiency on an HHV basis), representing overall plant-wide emissions (from 2 CT's) and accounting for electrical production by a steam turbine (i.e., emissions on a MW generation basis pro-rated to include steam turbine contribution). Values do not include duct burner emissions; assumed to be from CT's only. Small, medium and single cycle classes have no post-combustion controls, and achieve NO_X reduction through burner configuration (low- NO_X or ultra low- NO_X). Conversions based on U.S. EPA 40CFR60 F-factors to convert PPM NO_X to lbs NO_X /MMBTU..

[7] Facility's NO_X emissions are increased by 20% for large and medium facilities, and by 15% for small facilities, to account for higher emissions during heat rate and load variations. PM and SO_2 emissions are linked to fuel consumption and hence do not experience the same increases due to cycling / peaking.

[8] LNB - Low NO_X Burner for controlling NO_X.

[9] NO_X as NO. Small plants are based on typical low- NO_X burners (25 ppm @15% O_2) and medium and single cycle plants on ultra low- NO_X burners (9 ppm @15% O_2) from manufacturer (GE) data. Cycling is assumed to increase overall NO_X emissions by about 20% for medium units (heat rate and low load variations) and about 15% for small units (cycling duty). Conversions based on U.S EPA 40CFR60 F-factors to convert PPM NO_X to lbs NO_X /MMBTU, and adjusted for NO molecular weight.

[10] Based on 100% conversion of typical fuel sulphur from Ontario gas supply data at 0.24 grains S/100 scf (5.5 mg S/m3) with gas HHV of 1000 BTU/ft3 (~900 BTU/ft3 LHV). Emission factor equivalence of 0.0007 lb/MMBTU.

[11] All particulate from gas turbines is on the order of 1 micron, hence all PM is assumed to be $PM_{2.5}$ (= PM_{10}). Particulate is the total of the filterable, condensable and secondary (in-stack sulphate) fractions. Filterable PM is based on manufacturer's (GE/MHI) guarantee for typical turbines in each size class (5 lb/hr or 0.0055 lb/MMBTU for small; 9 lb/hr or 0.0055 lb/MMBTU for mid; 12 lb/hr or 0.0043 lb/MMBTU for large). Condensable PM is assumed equal to filterable particulate based on manufacturer's (GE) estimates and experience with similar projects in Ontario and California. Sulphate PM (0.0007 lb/MMBTU) represents secondary particulate formed as a result of reactions with NH_3 in the SCR (assumes all SO_4 reacts to form PM) and hence is only found in large class plants.

[12] Stack parameters are based on manufacturer's (GE/MHI) data for typical small and large 2 x 1 combined cycle plant designs with each turbine venting through an HRSG. Medium plant stack parameters are assumed to be median of small and large class parameters. Single cycle stack parameters are based on manufacturer's data (GE) and similar sized facility designs.

[13] Combined cycle exhaust temperature based on HSRG's extracting bulk of exhaust heat (T decrease from ~1100°F to 212°F). Exhaust temperature based on those achieved in similar 2x1 combined cycle plant designs in Ontario and US. Single cycle exhaust temperature based on similar facility designs.

Table A-4 Scenario 4 (Stringent Controls) Emissions Parameters

Facility [1]	OPG Lambton				OPG Nanticoke							
Unit/Flue [2]	1	2	3	4	1	2	3	4	5	6	7	8
Rated Power Output (MW)	485	485	498	498	490	490	490	490	490	490	490	490
Fraction of Total Available Power [3]	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%
Unit Generation (TWh/yr) [4]	2.26	2.26	2	2	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
Annual Generation (TWh/yr)	4.5		4		9.0				4.5		4.5	
Annual Utilization (ACF) [5]	53%		46%		53%				53%		53%	
Stack [2]	Stack 1		Stack 2		Stack 1				Stack 2			
Emission Controls [6]	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, OFA, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP	FGD, LNB, SCR, ESP
NOx as NO (g/kWh) [7]	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
NOx as NO (Mg/yr)	678	678	600	600	678	678	678	678	678	678	678	678
NOx as NO (Mg/yr)	1356		1200		2712				2712			
SO2 (g/kWh)	0.67	0.67	0.938	0.938	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
SO2 (Mg/yr)	1514.2	1514.2	1876	1876	1514.2	1514.2	1514.2	1514.2	1514.2	1514.2	1514.2	1514.2
SO2 (Mg/yr)	3028.4		3752		6057				6057			
PM10 (g/kWh)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
PM10 (Mg/yr)	22.6	22.6	20	20	22.6	22.6	22.6	22.6	22.6	22.6	22.6	22.6
PM10 (Mg/yr)	45.2		40		90				90			
UTM East (km)	379.818	379.818	379.906	379.906	577.69	577.69	577.69	577.69	577.428	577.428	577.428	577.428
UTM North (km)	4739.152	4739.152	4739.008	4739.008	4738.782	4738.782	4738.782	4738.782	4738.703	4738.703	4738.703	4738.703
Flue exit height above grade (m)	169.8	169.8	168.0	168.0	198.1	198.1	198.1	198.1	198.1	198.1	198.1	198.1
Flue exit diameter (m)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Flue exit flow rate (m^3/s) [8]	651	651	651	651	668	668	668	668	668	668	668	668
Flue exit velocity (m/s) [8]	53	53	53	53	52	52	52	52	52	52	133	133
Flue exit temperature (°C) [8]	33.17	33.17	33.17	33.17	34.04	34.04	34.04	34.04	34.04	34.04	34.04	34.04

Notes for Table A-4

[1] Modelled scenario generation based on Scenario 1 (Base Case) but with added emission control technologies.
[2] Each unit is routed to an individual flue in one of two stacks.
[3] Individual fraction of total available power for this scenario
[4] Generation is assumed to be divided evenly among units.
[5] Annual utilization of available capacity is based on proposed annual generation.
[6] SCR - Selective Catalytic Reduction units for controlling NO_X.
FGD - Wet Flue Gas Desulphurization units for controlling SO_2
LNB - Low NO_X Burner for controlling NO_X.
OFA – Over-fired Air for controlling NO_X.
ESP - Electrostatic Precipitator for controlling PM.
[7] NO_X is expressed as NO on a mass basis and therefore does not account for the relatively small mass of NO_2 emitted (≤ 2%).
[8] Flue exhaust parameters are based on Maximum Continuous Rating (MCR).

The CALMET model was used to interpolate observed meteorological data so as to provide representative 3-D, time-varying meteorological parameters for the CALPUFF model. The CALMET/CALPUFF study domain adopted for this project covers a region of southern Ontario that extends from Lambton in the west, to Ottawa in the east and from north of Sudbury to the southern tip of Point Pelee and encompasses the major populated areas of southern Ontario. The study domain covers a total of 432,000 km^2. The UTM coordinates of the study domain extents are provided in Table A-5.

Table A-5 CALMET Study Domain Coordinates

Domain Corners	Easting (km)	Northing (km)	Distance (km)
Lower Left	310.000	4620.000	Height 600 km
Upper Left	310.000	5220.000	
Lower Right	1030.000	4620.000	Width 720 km
Upper Right	1030.000	5220.000	

The horizontal grid spacing adopted for the CALMET modelling was 20 km, equating to 36 rows by 30 columns. By selecting this grid spacing, it was possible to maximize run time and file size efficiencies while still capturing the major topographic features in the domain that influence regional-scale wind flow patterns. To simulate pollution transport and dispersion in CALPUFF, it is important to be able to simulate the typically log-linear vertical profile of wind speed, temperature, turbulence intensity, and wind direction within the atmospheric boundary layer (i.e., within about 2000 metres above the Earth's surface). In an effort to limit the size of the CALMET output files and yet still capture this vertical structure, a total of eight vertical layers were selected. Within CALMET, vertical layers are defined as the midpoint between two layers or faces (i.e., nine faces = eight layers, with the lowest layer always being ground level or zero). The vertical faces used in this study are: 0, 20, 40, 80, 160, 320, 600, 1400, and 3000 m.

Land use in the study domain includes areas classified as forest, agriculture, water, and built-up / urban. Default land use parameters based on the USGS classification system were adopted in CALMET to produce surface geophysical grids for: surface roughness (Z_0), leaf area index (LAI), albedo, Bowen ratio, soil heat flux, and anthropogenic heat flux. A terrain grid at 20-km spacing was produced using digital elevation models and reformatted for input to CALMET.

The meteorological modelling used surface and upper air meteorological data from 1999 (i.e., 8760 hours). The year 1999 was selected as data for that year were already available in a readily usable format. The data for 1999 provide a good cross-section of typical large-scale weather patterns throughout the study area. The study could be enhanced by using more than a single year of meteorological data, but using just the 1999 data represented a reasonable approach consistent with the practical constraints of computer run time, file management, etc.

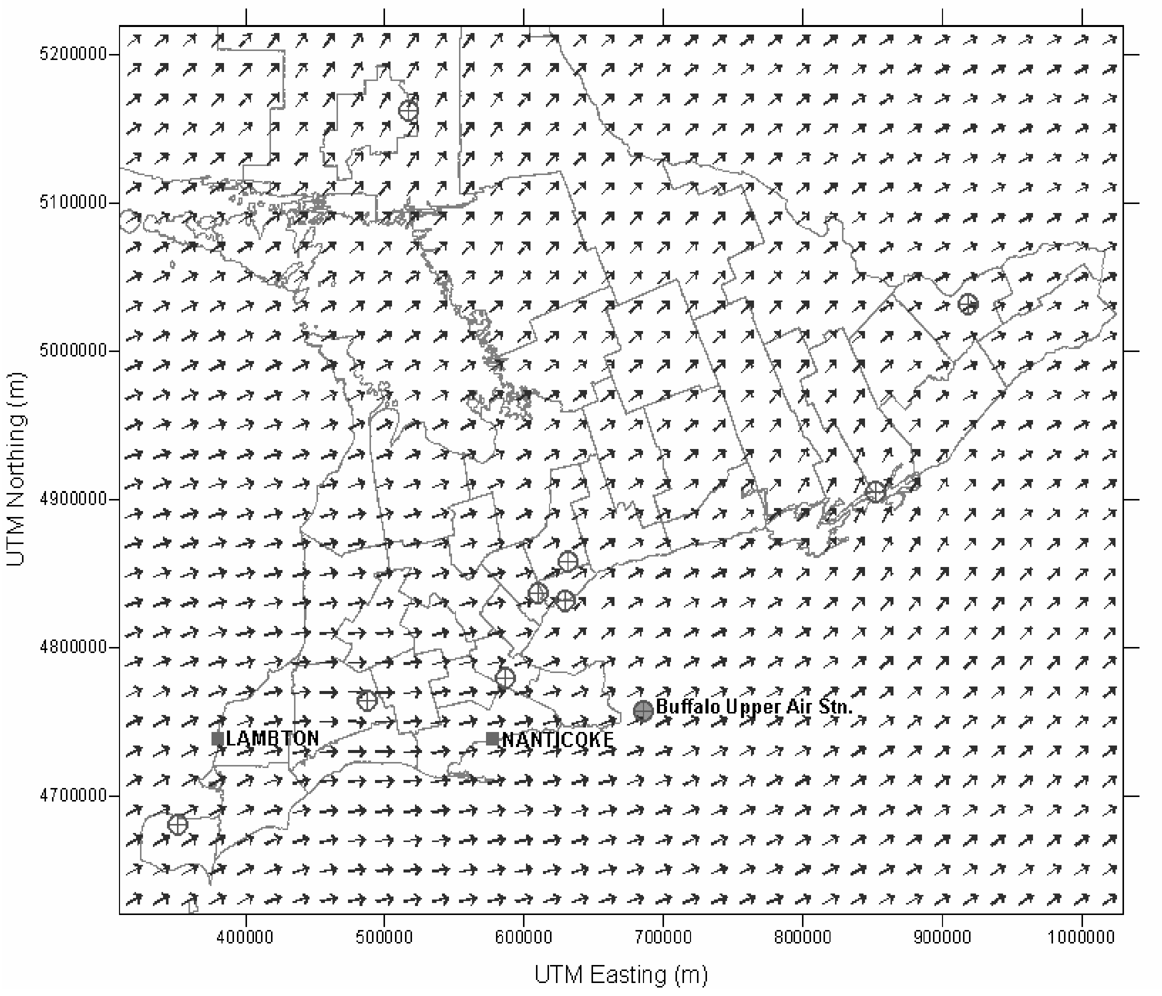
The meteorological observations used in CALMET consisted of vertical profiles obtained from twice-daily (0000 and 1200 GMT) upper air sounding at Buffalo International Airport, and hourly surface observations from Environment Canada meteorological stations at the following locations:

- Ottawa (Station #6106000);
- London (Station #6144475);

- Sudbury (Station#6068150);
- Hamilton (Station #6153194);
- Kingston (Station#6104146);
- Windsor (Station#6139525) and;
- Toronto stations (Stations #58733, 59999, 58665).

The locations of the upper air and surface meteorological stations are shown in Figure A-2.

Figure A.2 Meteorological Stations, and Sample Wind Vectors (July 16, 1999)



Precipitation data were not processed in CALMET and hence, were not used to account for wet deposition in CALPUFF. This conservative decision reflects the lack of available data and offsets some other modelling uncertainties that may err on the non-conservative side (i.e., exaggerate pollutant concentrations).

The available meteorological data were used to calculate surface wind fields within CALMET for each every hour of the year and for each grid cell in the domain.

A.3.2 CALPUFF

The contribution of power plants to annual average concentrations of primary PM_{10}, SO_2, NO_X, sulphate (SO_4^{-2}), nitrate (NO_3^-), and nitric acid (HNO_3) was predicted. Primary PM_{10}, particle nitrate, and particle sulphate concentrations were summed to arrive at total PM_{10} concentrations. Relationships between NO_X and volatile organic compounds (VOCs) and how they relate to ozone (O_3) in different parts of southern Ontario were developed from ambient monitoring data and used to derive a first-order approximation of ozone formation to estimate the contribution of power plant emissions to seasonally averaged peak 8-hour ozone concentrations. The air quality model outputs were summarized and reformatted for input to the health and environmental risk models.

The impacts of emissions from power plants on air quality were modelled using CALPUFF with meteorological inputs from CALMET. CALPUFF is a multi-layer, multi-species, non-steady-state puff dispersion model, which can simulate the effects of time and space varying meteorological conditions on pollutant transport, transformation, and deposition. CALPUFF uses the three-dimensional meteorological fields developed by the CALMET model. Although CALPUFF contains algorithms for near-source effects such as initial vertical plume rise, building wake downwash effects, interactions with terrain features that are smaller than the model grid, etc., these “local-scale” effects were not modelled given the regional context of the present study. Algorithms to handle longer-range effects such as pollutant removal (dry deposition), chemical transformation, vertical wind shear, etc. were applied.

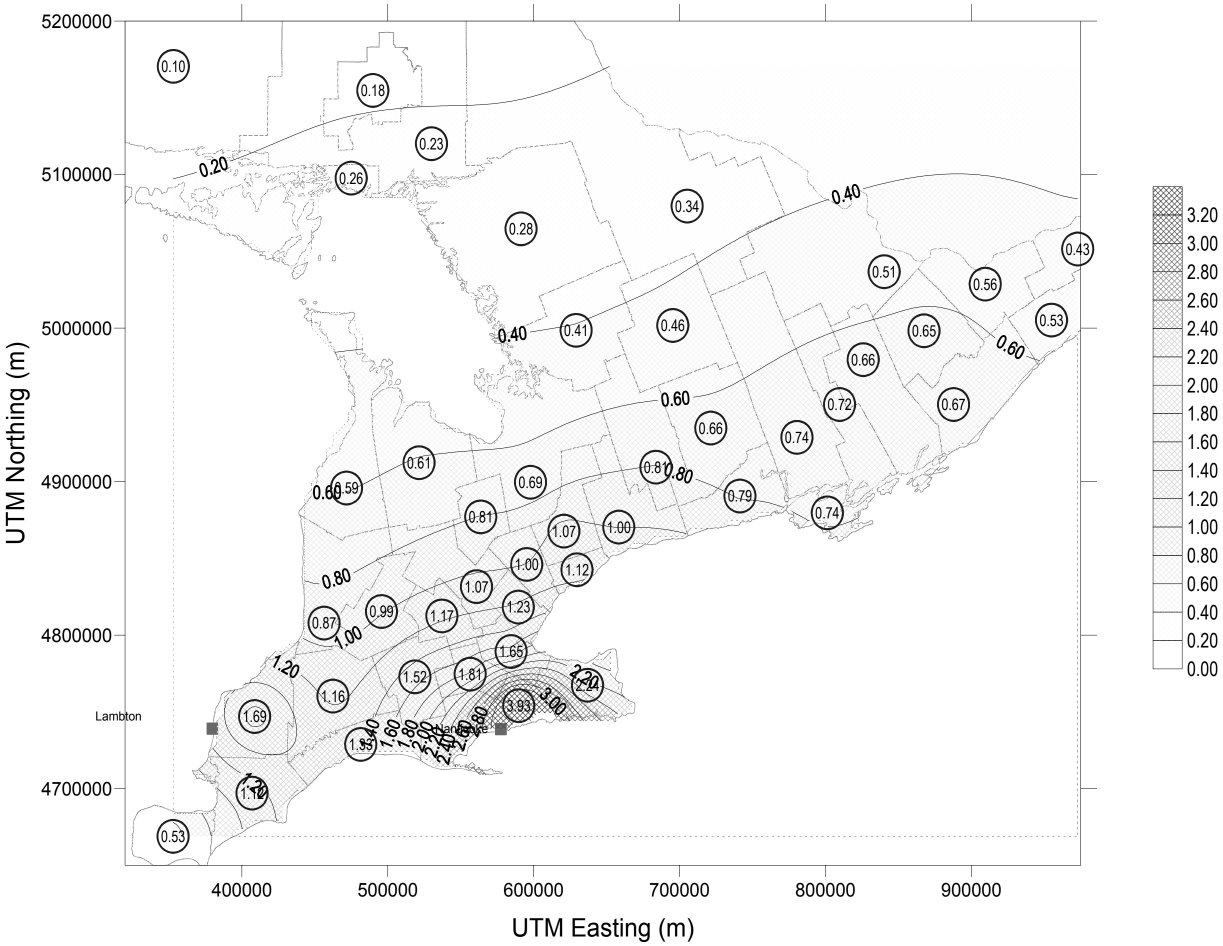
The CALPUFF model requires the user to define the location where concentrations are to be calculated (receptors). The CALPUFF model spatial domain coincided exactly with that used in CALMET. Forty-four census division receptors were used. Census division centroids were described by latitude and longitude coordinates converted into UTM Zone 17 (WGS84) coordinate pairs. The elevation in metres for each centroid was also determined. The location of each receptor, in relation to the census division it represents, is illustrated in Figure A-3. Note: each blue represents a CD centroid.

CALPUFF produces predicted concentration and deposition values for all meteorological and receptor combinations. The CALPOST program (an output management program) was used to extract the desired outputs from the CALPUFF model results. Further post-processing of the pollutants was performed to compute the sum of primary and secondary PM_{10}, and to calculate O_3 concentrations.

Atmospheric particulate matter (including PM_{10}) can be emitted directly by emission sources or can be formed in the atmosphere by chemical reactions involving precursor emissions. Specifically, emissions of SO_2, NO_X and volatile organic compounds (VOCs) can lead to the secondary formation of PM. As discussed in greater detail below, PM chemical transformation was modelled in CALPUFF to account for the conversion of SO_2 to sulphate (SO_4), and NO_X to nitrate (NO_3). Estimates of secondarily derived PM_{10} (i.e., particle nitrate and particle sulphate) were summed with primary PM_{10} concentrations to arrive at total PM_{10} concentrations at each receptor.

Predicted NO_X concentrations were further processed. Using a first-order approximation of ozone formation and an empirical ozone relationship based on measured NO_X and VOC in southern Ontario, ground-level ozone concentrations were derived. The methodology used for these estimates is detailed later in this section.

Figure A.3 Scenario 1: Forecast PM_{10} Concentrations ($\mu g/m^3$)



Some of the technical algorithms in the CALPUFF model of relevance include:

- *Dry Deposition*: A full resistance model provided in CALPUFF for the computation of dry deposition rates of gases and particulate matter as a function of geophysical parameters, meteorological conditions, and pollutant species was used.

- *Chemical Transformation*: CALPUFF includes options to parameterize chemical transformation effects using different schemes. The MESOPUFF II model based a five species scheme (SO_2, SO_4^{-2}, NO_X, HNO_3, and NO_3^-) was employed for this study. This option required inputs for background ozone and NH_3 concentrations.
- *Dispersion Coefficients*: Several options are provided in CALPUFF for the computation of dispersion coefficients. Dispersion coefficients from internally calculated sigma v and sigma w using micrometeorological variables (u*, w*, L, etc.) were adopted.

To calculate total PM_{10} concentrations contributed by power plants at each receptor, the CALPOST post-processor was used to extract predicted hourly concentrations ($\mu g/m^3$) of NO_3, SO_4 and PM_{10}. The annual concentrations of NO_3 and SO_4 at each receptor were converted to $(NH_4)_2SO_4$ and NH_4NO_3 using mass conversion factors of 1.375 and 1.290, respectively. The resulting ammonia sulphate and ammonia nitrate mass concentrations were then added to the primary PM_{10} concentrations to arrive at the total annual PM_{10} concentrations attributable to power plants at each receptor.

Ground-level ozone is an airborne pollutant that is not emitted directly, but is formed as a by-product of complex chemical interactions among other emitted pollutants, particularly NO_X emissions. CALPUFF does not have the capability of predicting the relevant chemical interactions. To deal with this issue, a simplified relationship between NO_X emissions and ozone production was derived. This relationship was applied to the predicted contribution of emissions from power plants to the average daily peak 8-hour NO_X concentrations during the smog season, yielding an estimate of the average contribution to peak daytime 8-hour ozone levels. Eight-hour average NO_X concentrations ($\mu g/m^3$) from 12:00-8:00 pm were extracted for each day during a period extending from May 1 to September 31 1999. These concentrations were then converted from $\mu g/m^3$ to parts per billion (ppb) at each receptor assuming an average ambient temperature of 25 ^{o}C and the molecular mass of NO_X is the same as NO_2 (46 g/mol).

The sensitivity of ground-level ozone to NO_X emissions varies from day-to-day and from place to place, depending on background concentrations of NO_X and VOCs, ambient temperature, cloud cover and other atmospheric parameters. For the present study, the power plant plumes were assumed to be exposed to high solar radiation levels (i.e., no cloud cover), warm temperatures, and highly NO_X-sensitive conditions at all times. It was further assumed that, under NO_X-sensitive conditions (commonly referred to as NO_X-limited conditions), the relative contribution of the power plants to ozone concentrations is related to the square root of the relative contribution to NO_X concentrations. To compute this relationship, it was necessary to obtain and pre-process information on background levels of NO_X and ozone in the study area, so that the power plant contribution could be calculated on a proportional basis. For this purpose, observed NO_X and O_3 8-hour (12:00-8:00 pm) concentrations for the year 1999 were extracted from the following list of air quality ambient monitoring stations.

- Burlington (Station #44008)
- Haliburton (Station #49010)
- Kitchener (Station #26060)
- Simcoe (Station #22071)
- Oshawa (Station #45025)

The data for Burlington and Oshawa were considered to be representative of large urban areas in the study domain. The data for Haliburton and Simcoe were considered to be representative of rural areas and the data for Kitchener were considered representative of small and medium-sized urban (e.g., transitional) areas. The average daily 8-hour background concentrations of NO_X during the smog season ranged from 4.8 ppb at the rural sites to 26.5 ppb in the urban areas; background O_3 concentrations were on the order to 45 ppb in both rural and urban areas. Modelled census division receptors were classified as urban, rural, or transitional to determine the appropriate background ambient concentrations of NO_X and O_3.

A.4 Air Quality Modelling Results

Predicted concentrations of PM_{10} and O_3 for each of the emission scenarios are summarized in Table A.6. The model results indicate that for the Base Case, the highest ozone (2 ppb)[17] concentrations resulting from CFG emissions occur in Haldimand-Norfolk Regional Municipality. The peak 8-hour daytime average concentration during the summer months attributed to this scenario reached about 2 ppb and the maximum 24-hour PM_{10} concentration reached about 4 $\mu g/m^3$.

Concentrations of both pollutants were much lower in all of the other three scenarios, with Scenario 4 (Stringent Controls) contributing the next most pollution (about 1 ppb ozone and 1 $\mu g/m^3$ of PM_{10}). Concentrations for both Scenarios 2 and 3 were much lower, with Scenario 3 (Nuclear/Gas) producing the lowest concentrations of all.

A.5 Model Limitations

Processes of pollutant transport, dispersion and transformation in the atmosphere are complex, meaning that air quality models tend to have fairly high levels of uncertainty. Some key sources of uncertainties are:

(i) uncertainties in the meteorological component arising from the limited spatial resolution of meteorological stations (particularly in the case of vertical profiles);
(ii) uncertainties in derived meteorological parameters (such as boundary layer depth and atmospheric stability parameters), which are not measured directly but estimated from other observed parameters;
(iii) uncertainties in hourly emissions profiles and stack parameters for the modelled sources;
(iv) inherent uncertainties in the equations used to represent complex physical and chemical atmospheric processes within CALPUFF; and,
(v) uncertainties in the simplified approach to the relationship between NO_X emissions and ozone production.

The meteorological modelling performed for this study is based on surface and upper air meteorological data from 1999 (i.e., 8,760 hours of recorded observations). The year 1999 was selected since the required data for that year were already available in a readily usable format. As well, 1999 provides a reasonably representative cross-section of typical large-scale weather patterns in southern Ontario. The study could be enhanced by incorporating meteorological data from multiple years.

The emission scenarios developed for this study were based on best estimates of power demand and probable infrastructure demands/limitations. Considerable effort was made to ensure that the model inputs were based on the best available estimates using the best available data. Particular attention was given to inputs having the greatest likely influence on the air quality model results.

Published studies of dispersion model accuracy for short-range dispersion applications suggest that errors in the highest estimated concentrations typically range between ± 10 and 40 percent (US EPA, 2003). Dispersion models are generally considered better at estimating longer time-averaged concentrations. Given, however, that the present study deals with long-range transport

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[17] All concentrations of pollutants reflect only that portion attributable to electricity generation emissions. Actual ambient concentrations will differ significantly due to the contribution of pollutants from many other sources.

rather than short-range transport, it is reasonable to expect that errors in predicted long-term concentrations are in the range from ± 10 to 40 percent. These error ranges apply equally to the modelled air quality results of all four scenarios.

A common practice with air quality modellers for dealing with high levels of uncertainty in dispersion models is to adopt modelling assumptions that tend to err on the high (i.e., conservative) side rather than the low side. In other words, air pollution modellers tend to use assumptions that will more likely overestimate rather than underestimate air pollution changes. These assumptions are:

i) Not including an allowance for wet deposition processes that tend to remove pollutants from the atmosphere, results in greater potential for pollution levels to be overestimated rather than underestimated
ii) Stack parameters were used that are more likely to underestimate rather tan overestimate vertical plume rise (and therefore overestimate local ground-level impacts) during peak production periods.
iii) By assuming that power plant plumes are exposed to NO_X-sensitive conditions at all times is more likely to overestimate rather than underestimate ground-level ozone concentration impacts

Adopting more refined modelling techniques that account for physical and chemical processes in greater detail could reduce some of the uncertainty. More refined models however, are impractical to run for a full year of meteorological data and are designed instead, to track shorter-term events. As computing technology improves, greater ability to use larger volumes of meteorological data will emerge. However, forecasting air quality 20 years into the future will always remain an uncertain undertaking.

Table A-6 CALPUFF Model Results by Scenario[18]

CALPUFF Model Results		Scenario 1 (Base Case)		Scenario 2 (CCGT)		Scenario 3 (Nuclear)		Scenario 4 (Control)	
		Ozone Conc. [1]	PM10 Conc. [2]	Ozone Conc. [1]	PM10 Conc. [2]	Ozone Conc. [1]	PM10 Conc. [2]	Ozone Conc. [1]	PM10 Conc. [2]
No.	Census Division Name	(ppb)	(mg/m^3)	(ppb)	(mg/m^3)	(ppb)	(mg/m^3)	(ppb)	(mg/m^3)
1	Stormont, Dundas and Glengarry United Counties	0.00	0.53	0.00	0.01	0.00	0.00	0.00	0.12
2	Prescott and Russell United Counties	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.10
6	Ottawa-Carleton Regional Municipality	0.00	0.56	0.00	0.01	0.00	0.00	0.00	0.13
7	Leeds and Grenville United Counties	0.01	0.67	0.00	0.01	0.00	0.00	0.00	0.16
9	Lanark County	0.00	0.65	0.00	0.01	0.00	0.00	0.00	0.16
10	Frontenac County	0.00	0.66	0.00	0.01	0.00	0.00	0.00	0.17
11	Lennox and Addington County	0.01	0.72	0.00	0.01	0.00	0.01	0.00	0.19
12	Hastings County	0.02	0.74	0.00	0.01	0.00	0.01	0.01	0.20
13	Prince Edward County	0.03	0.74	0.00	0.01	0.00	0.01	0.01	0.20
14	Northumberland County	0.05	0.79	0.01	0.01	0.01	0.01	0.02	0.22
15	Peterborough County	0.02	0.66	0.01	0.01	0.00	0.01	0.01	0.18
16	Victoria County	0.04	0.81	0.01	0.01	0.01	0.01	0.02	0.21
18	Durham Regional Municipality	0.04	1.00	0.02	0.02	0.01	0.01	0.01	0.26
19	York Regional Municipality	0.01	1.07	0.01	0.02	0.01	0.01	0.01	0.27
20	Toronto Metropolitan Municipality	0.03	1.12	0.02	0.02	0.01	0.01	0.01	0.30
21	Peel Regional Municipality	0.01	1.00	0.01	0.02	0.01	0.01	0.00	0.28
22	Dufferin County	0.05	0.81	0.00	0.02	0.00	0.01	0.01	0.21
23	Wellington County	0.09	1.07	0.01	0.02	0.01	0.01	0.03	0.28
24	Halton Regional Municipality	0.06	1.23	0.01	0.02	0.00	0.01	0.02	0.34
25	Hamilton-Wentworth Regional Municipality	0.05	1.65	0.01	0.02	0.00	0.01	0.02	0.44
26	Niagara Regional Municipality	0.34	2.24	0.04	0.02	0.03	0.01	0.09	0.57
28	Haldimand-Norfolk Regional Municipality	1.97	3.93	0.07	0.03	0.04	0.01	1.03	1.24
29	Brant County	0.08	1.81	0.01	0.02	0.00	0.01	0.03	0.45
30	Waterloo Regional Municipality	0.01	1.17	0.00	0.02	0.00	0.01	0.00	0.31
31	Perth County	0.05	0.99	0.00	0.02	0.00	0.01	0.02	0.28
32	Oxford County	0.12	1.52	0.01	0.02	0.00	0.01	0.04	0.40
34	Elgin County	0.14	1.33	0.01	0.01	0.00	0.01	0.06	0.39
36	Kent County	0.21	1.12	0.02	0.01	0.01	0.01	0.13	0.41
37	Essex County	0.01	0.53	0.00	0.01	0.00	0.00	0.01	0.18
38	Lambton County	0.43	1.69	0.03	0.02	0.02	0.01	0.28	0.70
39	Middlesex County	0.06	1.16	0.00	0.01	0.00	0.01	0.03	0.39
40	Huron County	0.04	0.87	0.00	0.01	0.00	0.01	0.02	0.27
41	Bruce County	0.01	0.59	0.00	0.01	0.00	0.00	0.00	0.18
42	Grey County	0.02	0.61	0.00	0.01	0.00	0.00	0.01	0.17
43	Simcoe County	0.02	0.69	0.01	0.01	0.00	0.01	0.01	0.20
44	Muskoka District Municipality	0.00	0.41	0.00	0.01	0.00	0.00	0.00	0.12
46	Haliburton County	0.01	0.46	0.00	0.01	0.00	0.00	0.00	0.12
47	Renfrew County	0.00	0.51	0.00	0.01	0.00	0.00	0.00	0.13
48	Nipissing District	0.00	0.34	0.00	0.01	0.00	0.00	0.00	0.09
49	Parry Sound District	0.00	0.28	0.00	0.01	0.00	0.00	0.00	0.08
51	Manitoulin District	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.07
52	Sudbury District	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.06
53	Sudbury Regional Municipality	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.05
57	Algoma District	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.03

Table 1 Notes:

[1] Peak daytime 8hr average ozone (O_3) concentrations were derived from modelled NO_X concentrations for 12-8 pm from May 1 to September 30.

[2] PM_{10} concentrations are peak are 24-hour average concentrations and include primary PM_{10} + nitrate + sulphate.

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[18] The values in this table are rounded to two decimal places. Impacts were modeled based using the reported precision from CALPUFF.

B APPENDIX B – MERCURY DAMAGES

B.1 Overview

Mercury (Hg) is an elemental metal that is naturally found in low background concentrations in the Earth's crust, plants, animals and humans (EPA, 1997). Mercury also has been used in human economies for centuries and for a great many uses.

Mercury enters the environment through natural and anthropogenic processes. Natural sources of mercury include volcanic eruptions, forest fires and releases due to flooding and/or erosion and transport by surface water. Anthropogenic releases can be categorized as incidental emissions, generally resulting from the combustion of materials with trace amounts of mercury (such as coal) or releases from deliberate uses, such as mercury-cell chlor-alkali plants or dental amalgams.

The relative contributions of anthropogenic and natural mercury have been the source of scientific debate. There has been considerable debate in Canada on the relative contributions of mercury from natural sources versus the releases to the environment from human activity. One of the challenges with this debate is the lack of accurate information on mercury emissions, past and present.

Scientists have analyzed sediment cores and determined that the levels of mercury in the environment today are about double what they were in pre-industrial times. They have also measured mercury in the atmosphere and found that concentrations continue to increase globally at over one percent per year. Total global mercury emissions are estimated to be about 5,000 tonnes per year (Mason and Sheu, 2002).

A recent study on the status of mercury in Canada represents the first time that consensus has been reached within the Canadian government on the relative importance of natural and anthropogenic sources (Canada, 2000). The best estimate for Canada and globally, is that 60 percent of emissions are anthropogenic and 40 percent are from natural sources. The estimated anthropogenic contribution ranges from 50 to 75 percent (US EPA, 1997).

The deposition, geobiocycling and re-emission, or "leap-frogging," of mercury makes it difficult to identify irrefutably mercury that originated from human activities. The health and environmental impacts of mercury are serious and have been well known for some time. For these reasons, the goal of many environmental policies, regulations and agreements is to virtually eliminate anthropogenic sources of mercury.

B.2 Chemistry, Environmental Cycling and Toxicity

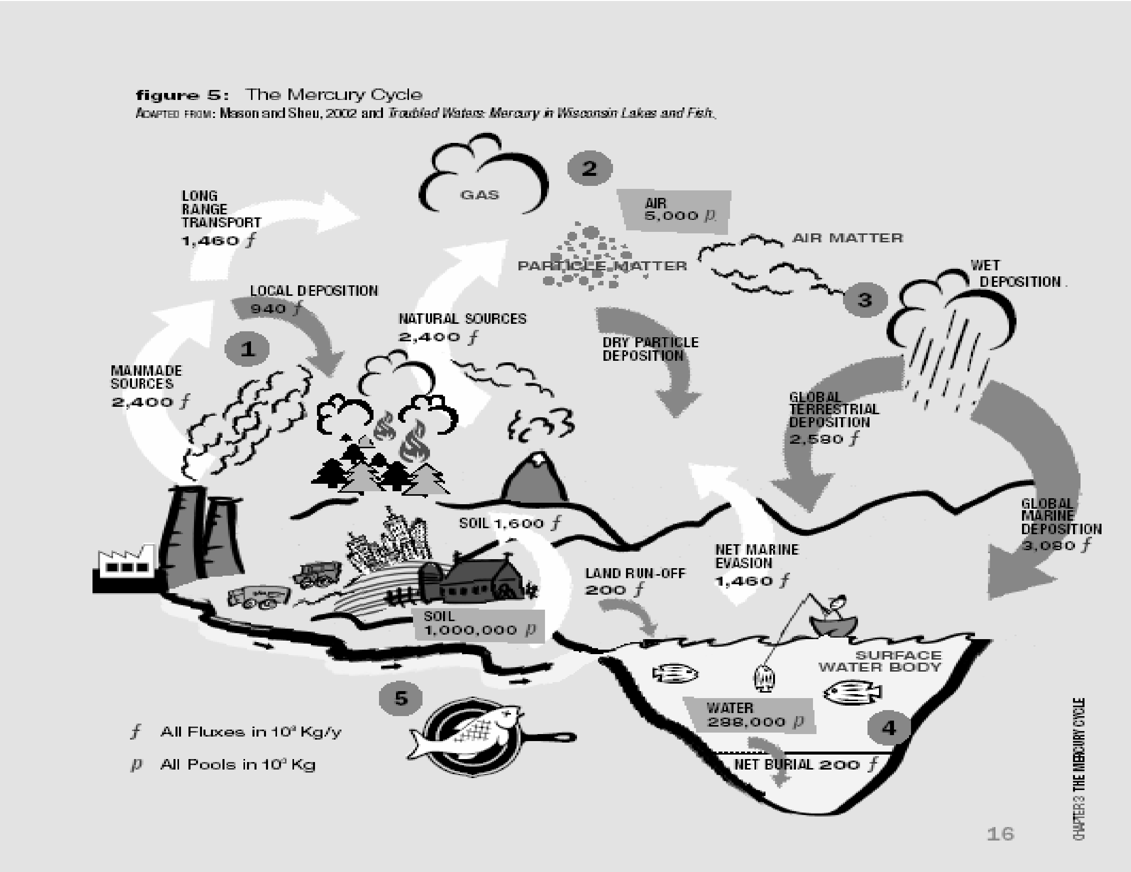
Mercury exists in three primary forms, elemental (metallic) mercury (Hg^0), inorganic mercury (Hg^{1+} or Hg^{2+}), and organic mercury (eg. methylmercury) (Health Canada, 1999b). Many compounds of mercury can be formed from mercuric mercury (Hg^{2+}) including organic and inorganic compounds (UNEP, 2002).

Mercury is highly mobile physically, chemically, and biologically. Mercury's properties, including toxicity, and chemical and physical behaviour depend on its oxidation states: Hg^0, Hg^{1+} (mercurous or Mercury (I)), and Hg^{2+}(mercuric or Mercury (II)). All forms of mercury are toxic and exhibit similarities in toxic effects, but some forms of mercury of mercury are much more toxic than others (ATSDR, 1999).

The most common form of mercury released into the air from natural processes is elemental mercury. Mercury, once released to the air either naturally (e.g., volcanic activity, forest fires) or as the result of human activity (e.g., through waste disposal and air emissions from fuel combustion), is highly mobile. Mercury can remain suspended in the atmosphere for more than 30 days during which time it can travel hundreds or thousands of kilometers before being deposited through either wet or dry precipitation (Institute for Environmental Studies, 1998).

Under certain environmental conditions, inorganic mercury undergoes a methylation process driven by microbial activity. The result is a chemical transformation to methylmercury. Methylmercury is cycles extensively and for an extended time in natural ecosystems. A primary avenue for entering the food chain is through invertebrates inhabiting marine or aquatic sediments. Once in the food chain, methylmercury biomagnifies such that organisms at the top of the food chain tend to exhibit the highest body burdens and are most likely to exhibit toxic symptoms. Many cases of toxic effects in humans are known where the primary source of contamination is through consumption of wild-grown foods, in particular fish (IJC, 1996). Human consumption of marine mammals and fish is a major source of mercury exposure (Gilbert and Grant-Webster, 1995).

Figure B.1 The Mercury Cycle[19]



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[19] Source: Pollution Probe, 2003; adapted from Mason and Sheu 2002

The levels of mercury found in terrestrial environments are usually not sufficiently high to pose a direct threat to the health of wildlife or humans. However, in aquatic environments, methylmercury contamination of fish and marine mammals is much greater and does pose a serious health risk. In addition to human health effects, many piscivorous species of fish and wildlife are at risk of mercury poisoning.

The human toxicology of mercury has been well understood for some time. Mercury exposure can lead to serious negative human health effects, the most severe involving the development and functioning of the central nervous system (Grandjean *et al.*, 1997).

B.3 Mercury Uses and Environmental Releases

Mercury use worldwide peaked in the 1970s, and has been declining ever since. In the United States and Europe, governments have banned the use of mercury in a number of products and placed strict disposal restrictions on products containing mercury. As a result of these actions, mercury is no longer used as a fungicide in paint and it has been all but eliminated from batteries manufactured in these countries. Figure B-2 illustrates the significant reductions in the use of mercury in consumable products in the United States. Mercury use in pesticides has also been reduced significantly as a result of stricter regulations. Changes to smelting technology have dramatically reduced mercury emissions in Canada.

Figure B.2 U.S. Industrial Mercury Consumption (1975-1997)

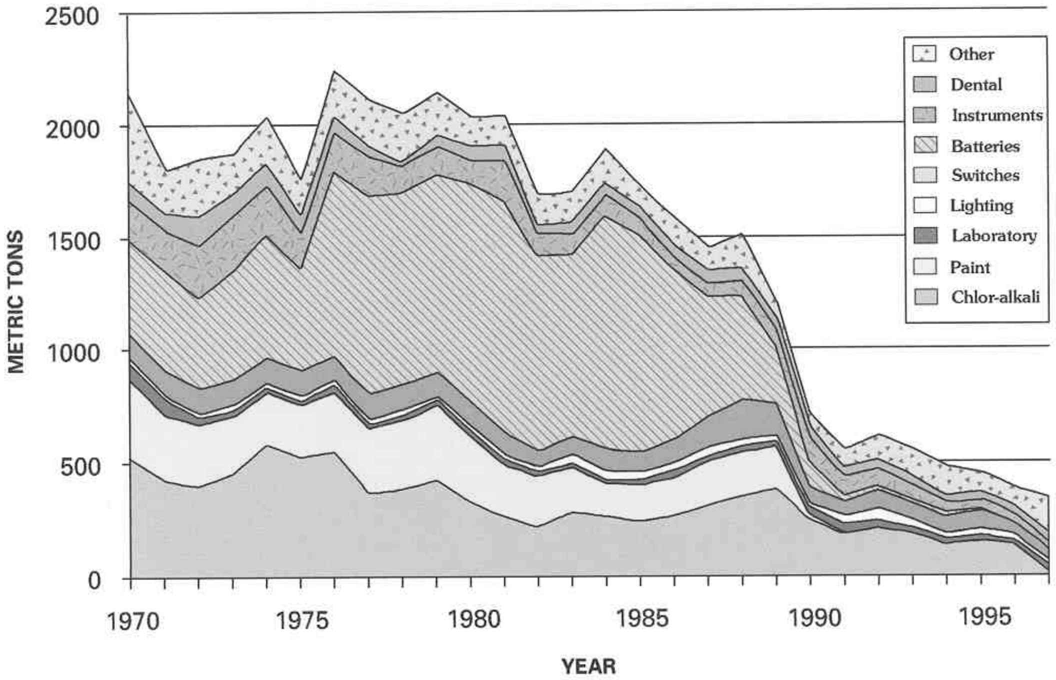


Figure 3. U.S. industrial reported consumption of mercury (1970–1997).

Large mercury reductions in Ontario have occurred due to declines in use of mercury-containing products (e.g. certain paints) and closures to mercury cell chlor-alkali plants. In Ontario, two sectors remain as the largest sources of airborne mercury emissions, waste incineration (hospital, hazardous and municipal) and coal-fired power plants. Ontario guidelines for mercury emissions from medical and municipal incinerators are expected to reduce emissions by 90 percent.

B.4 Mercury Transport and Deposition

Mercury is a global pollutant. Like other global pollutants, emission sources from around the world contribute to a global pool. Mercury, unlike other global pollutants such as CO_2 or CFCs, does not result in global system-scale impacts. Instead, mercury causes local-level impacts via mercury deposition, methylation, and biomagnification. Exposure is due to the combined effect of local and global emissions. For this reason, assigning the proportion of local damages attributable to local emission sources is greatly complicated. Much uncertainty exists around the proportion of the atmospheric mercury deposited in Ontario that is attributable to local sources. However, reductions in Ontario emissions would likely lead to proportional local improvements.

B.5 Coal-fired Generation Emissions

With significant reductions from most other sectors, CFG facilities are now the largest source of airborne mercury emissions in Ontario (and North America), contributing approximately 39 percent of Ontario's mercury air emissions. Furthermore, CFG facilities are the only sector in North America where mercury emissions are on the rise; this tend is due to increases in coal consumption.

The following series of maps (Figure B-3) suggests a likely connection between CFG-related mercury emissions and elevated environmental exposure. The data suggest that similar to acid rain, mercury deposition is concentrated in southern Ontario, southern Quebec and the Maritimes, and in the midwestern and northeastern states.

Several recent studies have shown that local mercury controls have led to environmental improvements. The Florida Department of Environmental Protection cites a 60 to 70 percent reduction in mercury concentrations in fish following a 100-fold decrease in industrial mercury emissions over two decades (Florida DEP, 2003). Similar studies have found a direct correlation between local emission reductions and ecosystem improvements in Sweden and Minnesota.

Furthermore, Ontario's CFG facilities contribute to the deposition of mercury in down-wind jurisdictions (e.g., the Maritimes and the Northeastern United States). Mercury levels are of particular concern in these areas. These damages should be considered when making policy decisions in Ontario.

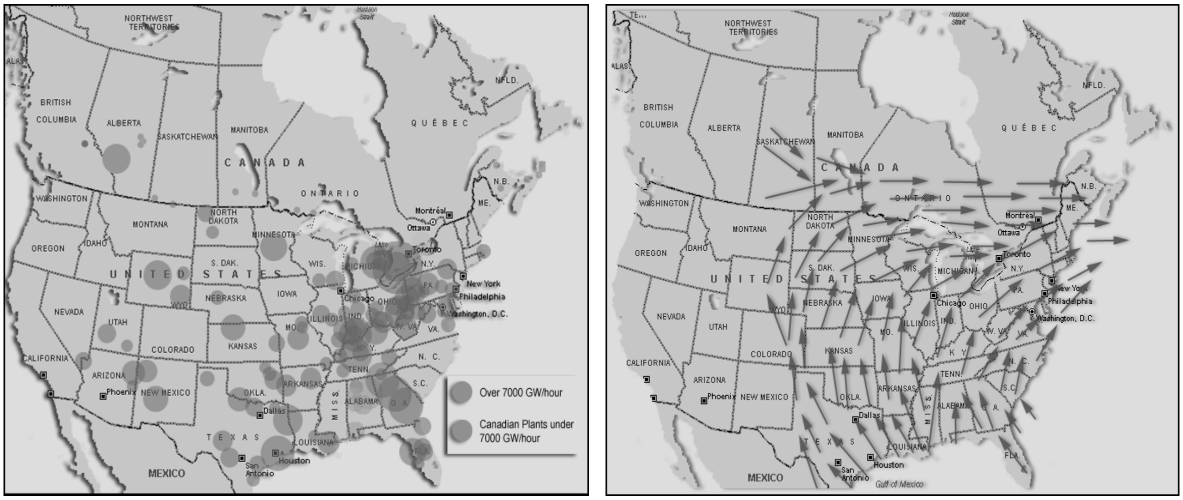
B.6 Human Health Effects

Methylmercury is a well-documented and potent neurotoxin. It has been seen to cause death and serious harm to humans when ingested. It causes neurological damage, developmental damage, damage to major organs, increased blood pressure, cardio-vascular disease, visual impairment, and is linked to reproductive and immune deficiencies. Methylmercury is one of the most toxic substances that humans are likely to be exposed to on a regular basis.

The history of human health effects associated with mercury exposure may be described as occurring in three major phases. The first phase involved direct exposure to very high concentrations of mercury (mainly inorganic mercury vapour). The toxicity of mercury vapour was known in Roman times when mercury was mined and made famous be Lewis Carroll's Mad Hatter. Mercury poisoning commonly afflicted beaver felt hat makers of the 19th Century as a result of prolonged exposure to the mercury used in the manufacturing process.

Figure B.3 Mercury Sources, Transportation and Exposure Effects

Coal-fired Power Plant Locations **Prevailing Wind Vectors**



Mercury Concentrations in Loon Blood (µg/g)

(Source: Lourie, 2001)

The second phase involved indirect acute exposure to high concentrations of mercury in food, in particular fish. The catastrophic poisonings in Minamata, Japan and Iraq provided modern examples of the toxicity of mercury. Minamata also provided the first evidence of the powerful biomagnifying properties of methylmercury. In Ontario, the Grassy Narrows-Wabigoon First Nation experienced severe mercury health damages from the consumption of contaminated fish downstream from an industrial chlor-alkali facility.

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The third phase in which we are currently engaged involves sublethal but potentially widespread health impairment associated with chronic, low-level exposure. Two of the most vulnerable human development stages to this type of exposure are the pre-natal and early childhood stages (Grandjean et al, 1997; UNEP, 2002).

The United States Environmental Protection Agency (US EPA, 2003c) reported:

- EPA has determined that children born to women with blood concentrations of mercury above 5.8 parts per billion are at some increased risk of adverse health effects. About 8 percent of women of child-bearing age had at least 5.8 parts per billion of mercury in their blood in 1999-2000.
- Current research indicates that there is no safe level of methylmercury in the blood within the range of exposures measured in the human studies of the health effects of mercury, which were as low as 1 part per billion. About 50 percent of the women of child-bearing age in the United States have at least 1 part per billion of mercury in their blood.

The U.S. Center for Disease Control estimates that 375,000 children are born each year in the United States with increased adverse health risks due to low-level mercury exposure (CDC, 2001).

B.7 Estimating Mercury-related Damages

Similar to the situation with ozone and PM several decades ago, the health risks of increased mercury exposure are generally understood but a strong epidemiological foundation is missing which would be suitable to derive quantitative damage forecasts. No quantitative estimates of the mortality or morbidity risks associated with environmental exposure to mercury have been produced for Ontario or elsewhere.

Nonetheless, using the scientific knowledge that is available leads to some clear conclusions, albeit qualitative ones. Mercury is not an essential element for the human body and no beneficial effects are known. Few if any substances share this distinction. Second, any level of mercury in the body of a developing fetus is considered to increase risk (Grandjean et al, 1997). There is no lower threshold below which the risks of impairment are eliminated. These facts lead to the conclusion that any reduction in mercury emissions produces a benefit for Ontarians, at least to fetus and young children. In fact, mercury is one of the few substances where no mercury is better than any mercury.

Fish consumption advisories are one of the most direct approximations of ecosystem damage. Fish consumption advisories have a direct and significant impact on recreational fishing benefits. Ontario mercury consumption guidelines for fish are based on federal guidelines supplemented by guideline recommendations by the World Health Organizations. Consumption restrictions for sports fish containing mercury begin at levels greater than 0.5 parts per million (ppm) with total restriction advised for levels greater than 1.5 ppm (MOE, 1997).

Mercury contamination accounts for 99 per cent of fish advisories in Ontario’s inland lakes. In Ontario, 39 per cent of sports fish (normally predatory species, such as pike, bass and walleye which are the primary species sought by anglers) in inland water bodies have consumption restrictions.

Jakus et al (2002) examined the benefits and cost of fish consumption advisories for mercury. Although the monetized benefits that they estimated are not directly transferable to Ontario, generically, the health damages on which their estimates were based certainly are. These health damages include:

- reduced IQ levels
- increased cardiovascular disease
- reduced motor skills
- increased adult dementia

As mentioned, several major barriers exist for developing quantitative estimates of mercury emission damages. One is that mercury released to the environment continues to cycle through the system for an extended period. As a result, emitted mercury may be responsible for a series of damages as it moves through an ecosystem. From a methodological perspective, perhaps the only means to deal with the environmental cycling nature of mercury is to develop a combined estimate of all of the impacts of mercury in an ecosystem and then ascribe the impacts to specific emission sources based on their relative contribution to the total mercury load to the ecosystem. Given the lack of a no-effect threshold for mercury exposure, this approach would provide a reasonable approximation of the attributable damages. Unfortunately, no suitable estimates of the total damages (both human and environmental) of mercury have been developed.

A study sponsored by the Office of the Attorney General in the State of Minnesota estimated a damage cost estimate per unit of mercury released. Minnesota shares many similar characteristics with Ontario. A primary cause for concern about mercury in Minnesota stems from the large number of lakes, the relative importance of tourism (e.g. angling) to the State economy, and the extent of fish consumption advisories due to high levels of mercury in fish. This study resulted in estimated mercury damage rates ranging from US$1,429 to US$4,359 per pound of mercury. In 2004$ Canadian, this damage range is approximately $3,000 to $10,000 per kg of mercury released. With 527 kg emitted from CFG facilities, the annual damage from mercury emissions is estimated at between $1,581,000 and $5,270,000.

Hagen et al., (1999) analysed the economic benefits of reducing mercury deposition in Minnesota as well. A contingent valuation methodology was used to determine willingness to pay for a reduction in local mercury deposition by 12%. The figure of 12% was based on a 50% reduction in emissions in the upper Midwest States. The derived willingness to pay was between US$119 and $US198 per household for a 12% reduction.

Actual mercury damage payments have been made in Ontario. With the English-Wabigoon River system, the Federal and Provincial governments, together with two companies, have paid nearly $17 million in damages. While this case involved quite high levels of mercury, the affected area represents a fraction of the total area and population of Ontario. Furthermore, the $17 million is not a final payment. Additional payments are expected in the future (INAC, 2004).

In conclusion, no comprehensive damage estimate for mercury emissions has been undertaken. Nonetheless, the scientific evidence of adverse impacts of mercury on the environment and human health is compelling. Of particular concern is the risk posed by mercury exposure during the early stages of human development. These impacts have long-lasting implications for society and the economy.