Cost Benefit Analysis:

Replacing

Ontario's Coal-Fired

Electricity Generation

Prepared for
Ontario Ministry of Energy

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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.

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.

The complete study is available on the Ministry of Energy's website at www.energy.gov.on.ca.