Notebook

Notebook provides data not easily found elsewhere and background descriptions of important aspects of the energy system. Contributions are invited.

1992 Carbon Dioxide Fact Sheet

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The 1992 issue of the *Carbon Dioxide Fact Sheet* follows the format of previous reports in this series in relying upon the *BP Statistical Review of World Energy* which is published every June following the year under review. This well-accepted source provides a comprehensive set of energy statistics for the world as a whole, classified by the principal nations and regions, on a timely basis. The data is especially useful for the estimation of carbon dioxide emissions from the fossil fuels since it provides a means of comparing these emissions throughout the world on a consistent basis as early as six months after the conclusion of the subject year.

In this note, internationally accepted coefficients are applied to energy consumption data to estimate carbon dioxide emissions for Canada, for other leading nations and regions of interest, and for the world as a whole. This is an overall or 'top-down' approach with two major inherent errors: other non-energy applications for the fossil fuels which may not lead to the emission of greenhouse gases are ignored as are the internal (or parasitic) use of fossil fuels in the production side of the energy industry which may be either not reported or under-reported in conventional

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consumption statistics. P.A. Okken has calculated that emissions of carbon dioxide as determined from global fuel statistics should be reduced some 2% to account for non-energy applications though this correction was not made here because of the balancing effect of emissions released during the production of energy. (P.A. Okken, *Calculation of Actual CO_2 Emissions for Fossil Fuels*, Energy Technology Systems Analysis Project, International Energy Agency Petten Workshop, The Netherlands, April 9-12, 1990). Carbon dioxide emitted from the calcining of limestone, released mainly in the cement and steel industries, was not included nor were other greenhouse gases considered, such as the methane escaping to the atmosphere from natural gas and coal during the production and distribution of these fuels. In 1992, the production of natural gas was reported as exceeding consumption by 3.2% (also 3.2% in 1991) suggesting there is still significant flaring or other losses in some production regions.

In addition to these difficulties, there is an inevitable uncertainty in global statistics dealing as they do with large flows of energy among a great many nations each of which may be in quite different economic circumstances. Some of the factors leading to discrepancies among estimates of carbon dioxide emissions have recently been surveyed by von Hipple *et al.* (David von Hipple, Paul Raskin, Susan Subak and Dmitry Stavisky, 'Estimating Greenhouse Gas Emissions from Fossil Fuel Consumption,' *Energy Policy*, Vol. 21, No. 6, pp. 691-702, (June) 1993.) What is important for the preliminary monitoring of carbon dioxide emissions, however, is the direction of change from year to year and its consistent measurement for both regions and major countries, including the patterns of consumption of the three fossil fuels in the respective individual primary energy balances. Nevertheless, the data reported here cannot be considered a substitute for a 'bottom-up' analysis of emissions, but such detailed studies inevitably take a good deal of time to conduct.

The same conversion factors were used as in previous years. The conversion of one million tonnes of oil equivalent (MTOE), the basic energy unit adopted in the *BP Statistical Review of World Energy*, was taken as 42 petajoules, the value also used by the World Energy Council. The specific factors applied to the three fossil fuels were those employed by the International Energy Agency: for oil - 19.9 million tonnes of carbon (not the dioxide) per exajoule (MTC/EJ); for natural gas - 13.8 MTC/EJ; and for coal - 24.1 MTC/EJ, all calculated on the basis of the higher heating value (HHV). The greatest uncertainty in the selection of appropriate factors centres on coal which may vary from one production region to another. Should it be desired to express emissions in terms of carbon dioxide rather than the carbon convention used in this note, the factor is 3.67.

The method of calculation of primary electricity (hydro and nuclear), and thus primary energy, employed in the *BP Statistical Review of World Energy* is now consistent with the convention adopted by the International Energy Agency, the World Energy Council, and some other such bodies, and which has also been adopted by the Department of Energy, Mines and Resources. Energy derived from hydraulic sources is reported as its thermodynamic equivalent of 3.6 MJ/kWh rather than the energy content of an estimated quantity of fossil fuel which would have been required to generate it. (Typically a conversion factor of 10.5 MJ/kWh was used previously for primary electricity.) For nuclear power, the factor adopted is 10.9 MJ/kWh which is equivalent to the 33% efficiency of conversion of heat to electricity characteristic of a modern nuclear power plant. (EMR converts nuclear energy at 3.6 MJ/kWh while the National Energy Board uses 12.1 MJ/kWh.) Though this change in methodology does not affect the calculation of carbon emissions in this note, ratios of carbon emissions to such important parameters as primary energy consumption will change substantially in a country such as Canada which has major generation of hydraulic energy and not negligible nuclear power. Care must thus be taken in applying data from past years. As is the prac-

Table 1: Carbon Emissions (MT) from Fossil Fuels — World

	1991	%	1992	%
Oil	2603.2	44.7	2614.7	44.8
Natural Gas	1029.4	17.7	1032.3	17.7
Coal	2190.5	37.6	2190.2	37.5
Total	5823.1	100.0	5837.2	100.0

Increase — 1992 over 1991: + 0.2%.
World emissions from the three fossil fuels: 1.1 tonnes C/person/year (1992).

Table 2: Carbon Emissions (MT) from Fossil Fuels — Canada

	1991	%	1992	%
Oil	62.5	51.6	63.9	51.8
Natural Gas	32.9	27.1	34.1	27.6
Coal	25.8	21.3	25.5	20.6
Total	121.2	100.0	123.5	100.0

Increase — 1992 over 1991: + 1.9%.
Canada as a percentage of world carbon emissions: 2.1% (1992).
Canada's per capita release of carbon: 4.5 tonnes C/person/year (1992).

Table 3: Carbon Emissions (MT) from Fossil Fuels — United States

	1991	%	1992	%
Oil	639.9	45.5	652.8	45.6
Natural Gas	286.7	20.4	296.9	20.7
Coal	478.7	34.1	482.4	33.7
Total	1405.3	100.0	1432.1	100.0

Increase — 1992 over 1991: + 1.9%.
US as a percentage of the world carbon emissions: 24.5% (1992).
US' per capita release of carbon: 5.6 tonnes C/person/year.

Table 4: Carbon Emissions (MT) from Fossil Fuels — Non-OECD Europe

	1991	%	1992	%
Oil	382.8	31.9	327.2	29.5
Natural Gas	382.0	31.8	362.3	32.7
Coal	435.3	36.3	419.5	37.8
Total	1200.1	100.0	1109.0	100.0

Decrease — 1992 over 1991: - 7.6%.
Non-OECD Europe as a percentage of world carbon emissions: 19.0% (1992).
Non-OECD Europe's per capita release of carbon: 2.7 tonnes C/person/year (1992).

Table 5: Carbon Emissions (MT) from Fossil Fuels — OECD Europe (including Turkey)

	1991	%	1992	%
Oil	532.9	54.3	540.3	55.9
Natural Gas	141.7	14.4	142.2	14.7
Coal	306.9	31.3	283.6	29.4
Total	981.5	100.0	966.1	100.0

Decrease — 1992 over 1991: - 1.6%.
OECD Europe as a percentage of world carbon emissions: 16.6% (1992).
OECD Europe's per capita release of carbon: 2.2 tonnes C/person/year (1992).

Table 6: Carbon Emissions (MT) from Fossil Fuels — China

	1991	%	1992	%
Oil	98.5	16.0	107.1	16.5
Natural Gas	7.8	1.3	7.9	1.2
Coal	510.0	82.7	533.4	82.3
Total	616.3	100.0	648.4	100.0

Increase — 1992 over 1991: + 5.2%.
China as a percentage of the world carbon emissions: 11.1% (1992).
China's per capita release of carbon: 0.5 tonnes C/person/year (1992).

tice in previous years, the *Review* does not report the substantial consumption of non-commercial energy around the world such as that derived from biomass sources. In the case of Canada, however, this source of energy may account for about 5% of total primary energy consumption. Unfortunately, some of the biomass energy consumed may be reported as 'solid fuel' in certain statistical sources and thus this energy may appear ultimately counted in part in the coal tables. In 1992, 90.8% of the world's commercial energy reported in the *Review* was derived from the three fossil fuels in 1992. This high proportion is an indication of the difficulties that will be encountered if it proves necessary to reduce carbon dioxide emissions substantially in the coming years.

At the United Nations Conference on Environment and Development (UNCED) held in Brazil in June of 1992, Canada adhered to international agreements concerned with global climate change and reiterated its commitment announced previously in the Green Plan to the stabilization of carbon dioxide and other greenhouse gas emissions at their 1990 levels by the year 2000. This decision makes it important to establish the level of emissions accurately in the 1990 base year. Consequently, A.P. Jacques of the Conservation and Protection Group of the Department of the Environment has prepared Report EPS 5/AP/4 entitled *Canada's Greenhouse Gas Emissions-Estimates for 1990* and dated December 1992, which may be obtained from Environment Canada, Ottawa, Ontario, K1A 0H3 (Fax: 819-953-9542). Total emissions of carbon dioxide in that year were 125.7 million tonnes of carbon as determined by the detailed methodology employed which, however, included several non-fossil fuel sources of this gas. Energy-related emissions in 1990 amounted to 121.4 million tonnes of carbon according to statistics published by the Department of Energy, Mines and Resources.

Canada was one of thirteen nations to sign an Implementing Agreement in the International Energy Agency (IEA) R & D activities in 1991 to evaluate options for the control of greenhouse gases which result from the utilization of the fossil fuels. Two periodicals have been started as a part of this activity in which fourteen countries and the European Community now participate. The first is a newsletter entitled *Greenhouse Issues* and is available free of charge. The second is an abstract service entitled *Greenhouse Gases Bulletin* (ISSN 0964-9107) and is available to those in member countries on the payment of a subscription fee of £60 per year. Both may be obtained from the IEA Greenhouse Gas R & D Programme, Coal Research Establishment, Stoke Orchard, Cheltenham, Gloucestershire, England, GL52 4RZ (Fax: +44 242 680758). This group organized the IEA Carbon Dioxide Disposal Symposium which has held at Christ Church College, Oxford, March 29-31, 1993 at which 62 presentations from 13 countries were made, including seven from Canada. These papers, which deal with the prospects for the capture and sequestering of carbon dioxide from the fossil fuels, were published as a separate volume of the journal *Energy Conversion and Management* (Pergamon Press) which appeared in August of 1993. The Second International Conference on Carbon Dioxide Removal will be held in Kyoto, Japan, in October, 1994.

The recent world political changes have also necessitated new regional classifications in the *BP Statistical Review of World Energy*. Europe is now divided into two major groups: OECD Europe which includes the European Community and member nations of the European Free Trade Association (ETA) such as Austria, Finland, Sweden and Switzerland but also including Turkey; and Non-OECD Europe which includes the republics of the former USSR together with the nations of eastern Europe: Bulgaria, the then Czechoslovakia, Hungary, Poland, Romania and the former Yugoslavia. A separate classification is also reported for the developing countries termed in the *Review* LDCs. The increase in carbon dioxide emissions from the LDCs was 4.9% in 1992 over 1991, and these countries now account for 30.8% of the world's total emissions of this gas. Per capita emissions in these countries were 0.4 tonnes C/person/year in 1992. There is every reason to believe the LDCs will account for a steadily rising proportion of the total as the years go by. China, for example, now produces and consumes more energy from coal than any other nation.

In 1992, world emissions of carbon from the three fossil fuels were 5.8 gigatonnes C in the form of carbon dioxide, an increase of only 0.2% from the previous year. Total primary energy consumption also increased 0.2% to

7794.2 MTOE, a level still somewhat below the high reached in 1990. Reliance upon oil remains high at 40.1% of the primary energy consumed.

Aside from the LDCs, whose primary energy consumption gained 4.8% over the previous year, increases were modest in most countries except Non-OECD Europe where there was a marked decline of 7.7%, no doubt due to the continuing economic dislocation in that region, and OECD Europe, where primary energy consumption fell 0.6%.

Two advanced European nations, France and Sweden, are following quite different energy strategies. France relies heavily upon nuclear power which in 1992 accounted for 77% of its electrical generation; nuclear generation increased 2.5% over 1992. In Sweden, which has announced plans to ultimately phase out its 12 reactors, nuclear generation accounted for 43% of the total but fell 17.2% that year. Notwithstanding this decline, Sweden actually obtained more of its total primary energy supply from nuclear power (38.1%) in 1992 than did France (37.5%). This unusual situation may, however, be an artifact of the statistics in that the extensive energy from biomass sources consumed in Sweden is not counted in the *Review*. Nevertheless, the latter country expects to reduce its already low per capita emissions of carbon by relying more extensively upon the biomass, by increasing its imports of natural gas, and by strengthening its already diligent conservation measures, all the while increasing economic output. French per capita emissions of carbon from the fossil fuels were 2.0 tonnes C/person in 1992 while those in Sweden were 1.9.

In the US, nuclear generation increased only 1.0% on the year ending a period of much higher annual gains suggesting nuclear output is approaching a plateau in that country as no new nuclear generating facilities have been ordered there for about two decades. Canada was the leading producer of hydroelectric energy followed by the US and Brazil.

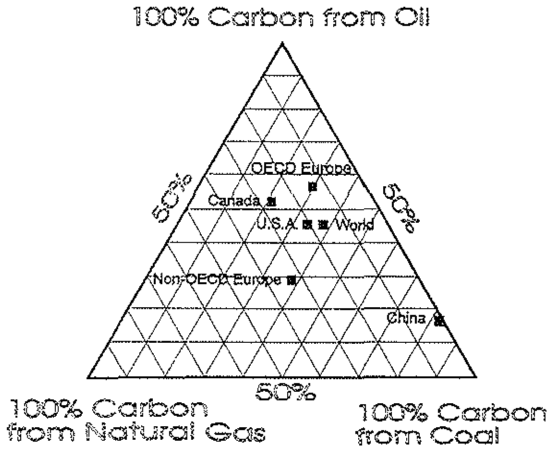

Figure 1: Emission of CO_2 from Fossil Fuels (1992)
Derived from *BP Statistical Review of World Energy*

Canadian carbon emissions from the fossil fuels increased 1.9% in 1992 over the year before reflecting some degree of recovery from the recession. Decreases had been experienced in the two previous years. Oil remained the largest source of carbon emissions accounting for 51.8% of the total while natural gas and coal accounted for 27.6% and 20.6% respectively. Canada is unusual in that emissions of carbon dioxide from the consumption of natural gas exceed those from coal. Canada continued to be responsible for 2.1% of the world's emissions of carbon from the fossil fuels and, with per capita emissions of 4.5 tonnes C/person/year, remained very high in the international rankings.

The Ternary Diagram illustrates the shares of carbon emissions from the three fossil fuels in 1992. Oil accounts for the highest share in the emissions from the OECD Europe Group of nations and coal from China, while natural gas is important in the Non-OECD Europe Group. Shares in the US were close to the world average, which is not surprising since that nation accounted for 24.5% of the total world emissions of carbon dioxide in 1992.

An Assessment of the Environmental Benefits of Demand Management for the Province of Ontario

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Introduction

Both demand and supply options have environmental impacts: demand management options through the production, use and disposal of products and materials, and supply options through air and effluent emissions.

This study focused on the environmental impacts of fossil-fired generation that is expected to be displaced by electrical efficiency improvement programs and higher efficiency standards in the province of Ontario by the year 2000. Air emission dispersions were modelled by generating station. The impacts of air emission reductions on human mortality, human morbidity, building materials, agricultural crops, forests and lakes and fisheries were quantified using dose-response functions taken from the literature or estimated for the province of Ontario. Environmental impacts were monetized using cost data specific to Ontario. The final outcome was an estimate of the environmental benefits associated with emission reductions in fossil-fuelled power plants due to efficiency improvements in electricity use in the province of Ontario.

This estimate of environmental benefits is subject to wide uncertainty and is incomplete: some air emission impacts are omitted; only generation, rather than full fuel cycle, impacts were included in the analysis; available data are often only rough approximations of those required for fully dependable estimates; and the environmental impacts of the demand management programs have not been netted out. In short, the information presented below is published here as a report on work in progress. The estimates we have produced may be of interest to others who work on environmental costs and their abatement.

Background

Ontario Hydro is a winter-peaking utility serving more than 3.6 million customers through 315 municipal utilities. In addition, it directly serves about 900,000 small business and residential customers in rural and remote areas and more than 100 industrial customers with demand greater than 5 MW.

In 1992 Ontario Hydro produced about 136.3 TWh of electricity (or about 22,000 MW of peak power). Four major sources were used to meet the electricity needs of the Province: nuclear (49%), hydraulic (27%), fossil fuel generation (21%) and purchases (3%).

Ontario Hydro has developed one of the most ambitious demand management programs in North America. By the year 2000, it is expected that the peak demand will be reduced by more than 3060 MW through demand management programs and 510 MW through government efficiency standards. The demand management program impacts include electrical efficiency improvements (1390 MW), load shifting (600 MW), peak clipping (830 MW) and fuel switching (240 MW). Efficiency standards include higher standards for major appliances, motors and improving building codes for new construction.

Electricity demand by the year 2000 is expected to be 168.5 TWh (or 24,235 MW) before the impact of electrical efficiency standards (3.1 TWh or 507 MW) and electrical efficiency improvements (7.4 TWh or 1389 MW) are taken into account. The load forecast is reduced to 158.0 TWh (or 22,339 MW) by the year 2000 after accounting for these impacts (Ontario Hydro, 1993b).

Based on the work done at Ontario Hydro to date, the reductions in air emissions from fossil-fired stations due to higher efficiency standards and program driven electrical efficiency improvements were quantified. There are no data available at this stage to quantify the impacts of load shifting, peak clipping and fuel-switching programs on fossil emissions.

Methodology

Reference Scenario vs All Supply Scenario

The proposed efficiency standards and demand management programs are expected to have significant impacts on supply side requirements. In order to assess the supply side environmental benefits of demand management, two alternative supply scenarios were developed: first, a reference scenario which includes supply as well as demand management options; second, a hypothetical all supply scenario where the efficiency standards and electrical efficiency improvements components of demand management were removed and substituted by supply generation options. Both scenarios were designed to meet the expected electricity needs of Ontario by the year 2000. The environmental emissions of the all supply scenario were compared with those of the reference scenario in order to isolate emissions reductions due to demand management.

Environmental Impact Assessment

There are four steps involved in quantifying and monetizing the supply side effects of demand management programs:

STEP 1: IDENTIFY AND ESTIMATE EMISSIONS

A first step in carrying out the environmental analysis is to identify and quantify emissions of the alternative supply options associated with demand management programs.

Environmental characteristics considered can be grouped into three broad categories: resource use (non-renewable fuel and land use), air emissions and wastes/ effluents (ash and thermal discharges). Due to data limitations, this study has focused on the impacts of air emissions avoided by demand management. In addition the quantification of impacts was limited to first order effects. For example, air quality impacts associated with the operation of a thermal generation station were estimated, but any impacts associated with the mining and transportation of the coal used to operate the station were not included. Further research is required in this area to assess the environmental impacts associated with the full fuel cycle.

The Power System Planning Division of Ontario Hydro has estimated air emissions by generating station that are displaced by demand management. The emissions are dependent on station design and operating parameters, capacity factors, fuel type and emission control technologies. The following air emissions have been identified and quantified by fossil station:

- sulphur dioxide (SO_2)
- nitric oxide and nitrogen dioxide (NO_X)
- carbon dioxide (CO_2)
- total suspended particulates (TSP)
- heavy metals, including mercury
- volatile organic compounds.

The contributions to ozone (O_3) and sulphate (SO_4) levels from the fossil system are calculated on the basis of estimated NO_X and SO_X emissions respectively.(2)

STEP 2: MODEL EMISSIONS DISPERSION

Several computer models have been used by Ontario Hydro's Research Division to estimate the dispersion of SO_2 and NO_X emissions from each station. Only the fate of these emissions within Ontario were considered in detail. Trans-boundary emission exports were identified but not studied in detail.

The province of Ontario was divided into grids with cells 5, 20 and 100 km square. The resolution was dependent upon population density. For each grid, the pollutant concentrations due to each scenario alone, and the total due to background (including pollution transported from US) was calculated (Kalvins *et al.*, 1992).

STEP 3: ESTIMATE PHYSICAL IMPACTS THROUGH DOSE-RESPONSE FUNCTIONS

Emissions from fossil-fired generating plants have a variety of impacts on the environment.

- Sulphur Dioxide is an acid gas precursor and is implicated in human health effects, lake acidification and damage to building materials.
- Nitrogen Oxides act as chemical precursors of acid rain and ground-level ozone and other oxidants. Ozone in turn contributes to adverse health effects and crop damage.
- Carbon dioxide contributes to global warming via the greenhouse effect.
- Particulates are fine particles that adversely affect visibility, act as carriers of trace metals present in the coal, contribute to health effects, damage building materials, and cause nuisance dust.
- Trace metals and mercury adversely affect human health and the environment.

A series of dose-response functions taken from the literature and previous research undertaken at Ontario Hydro were used to estimate the impacts of air emissions from the fossil-fired stations on major receptors.

Empirically estimated dose response functions for mortality and hospital admissions for total and respiratory disease groups have been estimated for the province of Ontario. Air pollutants considered include SO_2, SO_4, TSP, O_3 and NO_3 which are, in part, directly or indirectly produced by Ontario Hydro (Plagiannakos and Parker, 1988). Concentrations of carcinogenic trace elements in the vicinity of the fossil stations were estimated. The cancer risks were then assessed using unit factors (i.e., the probability of contracting cancer assuming that an individual is exposed to a unit concentration of the pollutant, over a lifetime) adopted in California (EPA, 1986).

The major pollutant that affects crops is ozone. The dose response functions for major crops (corn, soy bean, wheat, tobacco, white beans etc.) were obtained from the US National Crop Loss Assessment Network, assuming the cultivars grown in Ontario are the same. Crop production was obtained from the Ontario Ministry of Agriculture and Food (Kalvins *et al.*, 1992).

The impact on lakes was assessed with a model developed by ESSA Consultants and the Federal Department of Fisheries and Oceans. The model is driven by sulphate deposition and calculations were carried out for sixteen watersheds in Ontario. There were no data or models available to estimate the impacts of sulphates on fisheries (Kalvins *et al.*, 1992).

Damages to building materials due to exposure to SO_2 were estimated for eight materials (paints, carbon steel, aluminum, copper, zinc, building stone, brick and concrete) based on a series of algorithms containing equations that estimate the impact in dollar terms (Kalvins *et al.*, 1992).

The response of forests to air pollution is not well defined. The estimate of the impact of pollution on forests was based on studies of the sugar maple in two small regions of Ontario. These studies considered only the effect of sulphate and nitrate deposition on soil chemistry (i.e., the impact of O_3 on trees was not considered since this is not well known). Further research is required to better model the impact of pollutants on forests (Kalvins *et al.*, 1992).

While it is recognized that emissions also impact wildlife, the literature does not contain sufficient information to estimate dose-response functions with any degree of confidence.

It should be emphasized that although significant improvements have taken place over the last few years in better understanding the impacts of air emissions on sensitive receptors, further research is required to develop reliable dose-response functions for the quantification of these impacts.

STEP 4: MONETIZE ENVIRONMENTAL IMPACTS

There are two approaches to estimating environmental costs: the cost of control approach and the damage costing approach.

Ontario Hydro supports the damage costing approach to monetizing environmental externalities. This approach attempts to place dollar values on estimated physical impacts associated with various pollutants. While more difficult to estimate, the environmental costs estimated through this approach attempt to reflect actual damages to health and the environment. In this study, it was used to monetize those externalities which could be quantified and evaluated in dollar terms.

The environmental impacts estimated in Step 3 were monetized using for the most part Ontario specific cost data. Estimates of environmental costs produced in support of Hydro's export application to the National Energy Board (NEB) were applied. Damage cost estimates were produced by station and major sensitive receptor. The environmental cost estimates for CO_2 were developed based on a review of existing estimates from other jurisdictions.

Results

Reference Scenario vs All Supply Scenario

Two alternative scenarios to meet the load forecast for the year 2000 have been developed by the Power System Planning Division: a reference scenario which includes demand management, and a hypothetical all supply scenario where approximately 1900 MW (or 10.5 TWh) of demand management (electrical efficiency improvement programs and efficiency standards) is replaced with alternative generation. It was estimated that by the year 2000, 8.75 TWh or 83% of demand management could be replaced by existing fossil generation with the remainder provided by existing nuclear generation. Table 1 shows the amount of expected fossil generation by station under the two scenarios.

Under the all supply scenario the fossil generation is expected to be 38% higher than the reference case by the year 2000.

It should be emphasised that the above estimates are very uncertain. The fossil system is a "swing" resource which is used to accommodate the difference between total demand and

Table 1: Ontario Hydro's Fossil Generating System

Station	1991 Gross Generation (TWh)	Year 2000 Fossil Generation			
		Reference Scenario (TWh) (a)	All Supply Scenario (TWh) (b)	Increase in Generation	
				(TWh) (b)-(a)	(%)
Lakeview	4.33	1.23	1.69	0.46	37
Nanticoke	18.20	11.15	16.73	5.58	50
Lambton	6.05	8.19	9.87	1.68	20
Lennox	1.00	0.48	0.66	0.18	37
Atikokan	0.73	0.78	1.08	0.30	38
Thunder Bay	1.27	1.45	2.00	0.55	38
	31.58	23.28	32.03	8.75	38

Source: Power System Planning Division, Ontario Hydro

the output provided by baseload resources. The future energy output required from the fossil system is difficult to specify because of the uncertainty in load growth and the uncertainty regarding the availability of other generation.

Quantification and Dispersion of Air Emissions

The emissions by the coal-fired stations are dependent on station design and operating parameters, capacity factors, type of fuel and emission control technologies. Both scenarios have the same control technologies by the year 2000 and are designed to meet the following environmental and operating regulatory requirements:

- SO_2 emissions held to less than 175 Gg per annum by 1994, and
- NO_X emissions held to less than 38 Gg per annum by 2000.

These levels are also consistent with international and bilateral environmental agreements currently entered by Canada. Estimates of emissions to the atmosphere and waste by-products for the year 2000 were produced for the two scenarios. Table 2 below provides these emissions on a system wide basis for the two scenarios.

Using several short range and long range pollution transport models, the dispersions of Ontario Hydro SO_2, NO_X and TSP emissions were simulated by station for each scenario. The formation and dispersion estimates of secondary pollutants such as SO_4 and O_3 were based on the SO_2 and NO_X modelling results.

Ontario Hydro's contribution to SO_2 and NO_X emissions was approximately 16% of total Ontario emissions in 1991. These emissions contributed roughly 2% to total SO_2 and NO_X deposition in Ontario. This is because a large fraction of pollution in Ontario is trasported from United States. Similarly the CO_2 emissions represent 14% of total anthropogenic CO_2 emissions in Ontario. Ontario Hydro's contribution to the background levels of SO_4, O_3, and TSP was estimated to be less than 2%. Preliminary estimates of annual mercury emissions from fossil generation indicate that Ontario Hydro could contribute 20-30% of the anthropogenic mercury emissions in Ontario (Ontario Hydro, 1993a).

It was estimated that approximately 45-55% of sulphate emissions and 25-45% of nitrate emissions are deposited outside of Ontario. Only a negligible portion of particulates were estimated to disperse beyond Ontario's bound-

Table 2: Ontario Hydro's Emissions from the Fossil System

Emissions to Atmosphere	1991 Ontario Hydro Emissions (Gg)	Contribution to Ontario's Total Emissions (%)	Year 2000 Fossil Generation Emissions			
			Reference Scenario (Gg)	All Supply Scenario (Gg)	Increase in Emissions	
					(Gg)	(%)
SO_2	166.0	16	97.79	143.29	45.5	47
NO_X	55.4	16	23.46	33.50	10.0	43
CO_2	27,000	14	20,070	27,580	7510.0	37
Part.	8.4	N/A	6.00	8.48	2.5	41
Mercury	0.002	20 - 30	0.001	0.0019	0.0	42
Waste	1100	N/A	623	852	229.0	37
Trace Metals	N/A	N/A	1.003	1.442	0.4	44

Source: Power System Planning Division, Ontario Hydro

aries.

Annual emissions of SO_2, NO_X, TSP and CO_2 displaced by demand management were estimated to be 45 Gg, 10 Gg, 2.5 Gg and 7510 Gg respectively by the year 2000. These represent an average increase of emissions of about 40% under the all supply scenario. Similar changes were estimated for mercury, ash, and trace metals.

Quantification of the Impacts

Table 3 below quantifies the impacts of Ontario Hydro air emissions for each scenario.

The difference in impacts between the two scenarios represents the environmental benefits of displacing fossil-fired electricity generation with electrical efficiency improvements. It is assumed here that the demand management programs will be properly designed so that their environmental costs will be minimal.

There are two components to the human health impacts associated with displacing fossil-fired generation with demand management. First, there is a predicted reduction in premature mortality of two shortened lives per annum attributable to displaced fossil generation by the year 2000. Second, hospital admissions are estimated to be reduced by approximately 477 per year. Damage to Ontario crops is expected to be reduced by about $2.4 million (1991 Can$) and to building materials by about $2.1 million (1991 Can$).

Due to data and model limitations, the impacts of displaced fossil-fired generation on forests, lakes, fisheries and wildlife have not been estimated. Also possible environmental impacts associated with demand management programs have not been included in this analysis. Further research is required in these areas.

Monetization of Impacts

The dollar costs of environmental damages per receptor estimated for the NEB export studies were used to develop preliminary estimates of the monetary benefits associated with a reduction in fossil generation due to demand management (Ontario Hydro, 1991). Table 4 below shows the environmental benefits of demand management associated with human health, crops and building materials.

In the studies submitted to the NEB, a value of $4 million (1988 Canadian dollars) per statistical life was adopted to estimate the economic value of a change in the risk of mortality. This value falls within the range of values contained in the literature regarding valuation of statistical life. The value of $4 million has been converted into 1992$ and adopted for the purposes of this study. As shown in Table 4, a monetized benefit of $9 million associated with reduction in premature mortality is realized from demand management displacing fossil-

Table 3: Environmental Impacts of Fossil Generation in Ontario

Type of Impact	1991 Ontario Total	Year 2000 Fossil Generation Impacts			
		Reference Scenario	All Supply Scenario	Increase in Impacts	
				Impact	%
Mortality/Yr	66367	5	7	2	30
Hospital Admissions/Yr	1,147,399	1,160	1,637	477	29
Crop Damage (k$1991/Yr)	2,545,000	3,824	6,189	2,365	38
Building Materials Damage (k$1991/Yr)	116,000	5,237	7,377	2,140	29

Source: Energy Economics Section, Economics & Forecasts Division, Research Division, Ontario Hydro

Table 4: Environmental Benefits of Demand Management (1992 Can$)

Type of Impact	Year 2000 Predicted Impacts from Demand Management			
	Outcomes	Per Unit Values (000's)	Monetized Benefit (Millions)	Monetized Benefit (cents/kWh)
Mortality	2	4726	9.4	0.1041
Hospital Admissions	477	45	21.3	0.2433
Crop Damages (Millions)	2.4	N/A	2.4	0.0274
Building Materials (Millions)	2.2	N/A	2.2	0.0248
			35.3	0.3997
CO_2 (Gg)	7510	$1.50-$42 /tonne	11 - 315	.13 - 3.6

Source: Energy Economics Section, Economics & Forecasts Division, Ontario Hydro

fired generation. This represents 26% of the quantified environmental benefits (excluding CO_2 impacts) associated with the reduction in fossil generation resulting from demand management.

The economic value of reduced hospital admissions is based on medical costs, lost income (including reduced personal income taxes) and losses in time spent on housekeeping. A risk aversion factor of 1.97 based on the ratio of insurance premiums to insurance claims for incomes lost and health costs not covered by social insurance (provided by Canadian Life and Health Insurance Association for 1988) was applied to those costs borne directly by the individuals.

The intent of these adjustments is to value each component of the costs from the point of view of those individuals at risk. As a result, a distinction is made between the portion of costs that are likely to be incurred directly by the individuals suffering from illness due to the incremental emissions (ie., lost incomes net of tax, household work and interrupted activities) and those which will be shared by the community at large (reduced taxes and medical costs). This methodology provides an approximation of the value that individuals place on such losses. A monetized benefit of $21 million associated with a reduction in hospital admissions is realized from displacement of fossil generation by demand management. This represents approximately 61% of the total quantified environmental benefits (excluding CO_2 impacts) of demand management in this scenario.

A market-based approach was used to estimate the monetized benefits associated with reduced crop losses. The cost of agricultural crops was estimated using the most recent information from the Ontario Ministry of Agriculture and Food. The average of total farm cash receipts for the most recent three year period was calculated. This was multiplied by an estimate of the average yield loss for all crops grown in Ontario. The result represents the dollar value of crop losses due to incremental fossil generation. The monetized benefit, as shown in Table 4, is approximately $2.5 million or 7% of the total quantified benefits when the CO_2 estimates are not included.

In the study for the NEB, two types of losses were considered for building materials: the replacement cost for physical deterioration of materials and the cleaning cost for soiling of exterior walls and windows. The estimates were based on a series of algorithms containing equations that estimate the impacts in dollar terms. Building materials account for $2 million or approximately 6% of the monetized benefits (excluding CO_2 impacts) associated with the reduction in fossil generation from demand management.

A wide range of estimates for costs per tonne of CO_2 emitted (from $1.5 - $42 Can. 1992$) exists. For illustrative purposes, Table 4 presents estimates of environmental benefits associated with CO_2 based on range values adopted by other jurisdictions. However, these values have not been included into the calculation of supply side benefits from demand management as these estimates are, for the most part, based on the cost of control approach and there is very little knowledge of the effects of global climate change from CO_2 emissions at the present time.

The estimates contained in Table 4 above are very preliminary and subject to change as current research progresses. A high degree of uncertainty exists with dose-response functions and monetary estimates. In addition, it is not possible to place a monetary value on the full range of impacts at the present time due to inadequate information. Further, some impacts have not been identified or included in this analysis of damages due to inadequate information. As methods improve, additional impacts will be incorporated into the analysis.

Conclusion

This study focused on the environmental impacts of air emissions expected to be displaced by demand management in the province of Ontario by the year 2000.

The estimated impacts of fossil emissions on human health, crops and building materials were significant. Emissions to the atmosphere would have been increased by about 40% and the environmental impacts by more than 30% in the absence of demand management programs. The annual monetized environmental benefits of the demand management by the year 2000 were estimated at 0.40 cents/kWh excluding CO_2 impacts. The health benefits accounted for 90% of the total quantified environmental benefits of demand management. These values are comparable to the estimates produced for the NEB export studies and the Bonneville Power Administration (Bonneville Power Administration, 1991).

Due to limitations in the models and the available data the impacts of air emissions on forests, lakes, fisheries and wildlife have not been estimated. In addition, the full fuel cycle impacts as well as the impacts of land used, wastes and effluents (ash and thermal discharges) from the stations have not been estimated. Also possible environmental impacts of demand management programs have not been included in this study.

It should be emphasized that there is a wide uncertainty associated with the above estimates. Further research is in progress at Ontario Hydro to improve the data bases and the models used to quantify and monetize the environmental impacts of fossil-fired generation.

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