IC 279

FOREWORD

Previous Mines Branch inventories of air pollution resulting from fuel combustion have been based on current trends which, if projected to 1980, warn of a general deterioration of the air environment.

This study was undertaken to evaluate the effects of applying abatement measures, and it appears that the air environments in areas of population concentration can be significantly improved from 1980 to the end of the century. None-the-less, there is a risk that the air may be dirtier in some areas, depending upon fuel selection.

John Convey,
Director,
Mines Branch.

November 1971.

AVANT-PROPOS

Les inventaires antérieurs de la Direction des Mines sur la pollution atmosphérique résultant de la combustion de combustible ont été basés sur les tendances courantes. Si on les prévoit jusqu' en 1980, il y aura une détérioration générale de l'environnement atmosphérique.

On a entrepris cette étude pour évaluer les effets de l'application des mésures d'abaissement, et il paraît que les environnements atmosphérique dans les régions de concentration de population peuvent être grandement améliorer à partir de 1980 jusqu' à la fin du siécle. Néamoins, il se peut que l'atmosphère puisse être plus sale dans quelques régions dépendant de la sélection de combustible.

John Convey,
Directeur,
Direction des Mines.

Mines Branch Information Circular IC 279

FUEL CONSUMPTION AND AIR POLLUTION TRENDS IN CANADA*

1965 - 1980

by

E.R. Mitchell**

ABSTRACT

A projection of fuel consumption to 1980 anticipates a continued strong growth rate of 6.5% per annum. Thus, it is possible that fuel consumption in 1980 will be 48.9 million tons of coal, 35.5 million of which will be needed for electric power generation, 796.5 million barrels of liquid fuels, and 2.5 trillion cubic feet of natural gas.

In describing the impact of the resulting pollution on the air environment, the paper shows that, by applying technically feasible abatement measures in 1975, about 6.9 million net tons of harmful pollution can be avoided in 1980. This reduction would be larger if, after 1970, more coal burning were not projected for thermal power generation. Despite this, the 1980 pollution burden will be 33% below the 1970 level. After 1980, the pollution burden will increase with population growth and, all things remaining equal, the 1970 level of pollution will return in the year 2004.

To accomplish this significant feat, it is roughly estimated that a capital expenditure of $1.6 billion will be needed by 1980 plus $300 million per year for automobile pollution control devices starting in 1975. Despite this large expenditure the paper indicates that, in 1980: (1) the air environment will appear dirtier in the regions where coal is burned for power generation (see Appendix I, item 1), because of a 151% increase in particulate emissions even with efficient electrostatic precipitators, but cleaner in the vicinity of steel mills and mineral processes where dust collectors are being installed; (2) odours from oil refineries, paper mills and other processes will continue but (3) the air will be more pleasant to breathe, and maybe healthier, in urban areas.

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*A study initiated by the Energy Sector, Department of Energy, Mines and Resources, Ottawa, Canada.

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Direction des Mines

Circulaire d'information IC 279

LES TENDANCES DE LA CONSOMMATION DE COMBUSTIBLE ET DE LA POLLUTION ATMOSPHÉRIQUE AU CANADA*

par

E.R. Mitchell**

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RÉSUMÉ

On prévoit la consommation de combustible jusqu'en 1980 à un taux toujours grandissant de 6.5% par année. Il est possible en 1980 alors de consommer en combustible 48.9 millions de tonnes de charbon, dont 35.5 millions seront nécessaires à la production d'énergie électrique, 796.5 millions de barils de combustibles liquides et 2.5 trillions de pieds cubes de gaz naturel.

En décrivant l'impact de la pollution résultante sur l'environnement atmosphérique, ce circulaire illustre qu'en appliquant des mésures d'abaissement techniquement possibles en 1975, environ 6.9 millions de tonnes nettes de pollution nuisible peuvent être évités en 1980. Cette réduction serait plus considérable si, après 1970, la combustion de charbon n'était pas prévue pour la production d'énergie thermique. Malgré cela, le fardeau de pollution en 1980 sera 33% inférieur à celui de 1970. Après 1980, le fardeau de pollution augmentera avec l'accroissement démographique et, toutes choses restant égales, le degré de pollution de 1970 reviendra en 2004.

Pour effectuer cet exploit significatif, on estime qu'il faudra dépenser en capital 1.6 billions de dollars pour 1980 plus 300 millions de dollars par année sur les appareils pour le contrôle de la pollution causée par les automobiles commençant dès 1975. Malgré ces grosses dépenses, le circulaire indique qu'en 1980: (1) l'environnement atmosphérique paraîtra plus sale

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* Une étude inititiée par le secteur de l'énergie ministère de l'Energie, des Mines et des Ressources, Ottawa, Canada.

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dans les régions où on utilise la combustion de charbon dans la production d'énergie (voir appendice I, article 1) à cause d'une augmentation de 151% dans les émissions de particules malgré l'aide efficace des précipitateurs électrostatiques, mais l'environnement atmosphérique paraîtra plus pur dans le voisinage des usines d'acier et de procédés minéraux où on installe des collecteurs de poussières; (2) les odeurs émanant des raffineries de pétrole, des papeteries et autres procédés continueront mais (3) l'air deviendra plus agréable à respirer, et peut-être plus sain dans les régions urbaines.

CONTENTS

TABLES

INTRODUCTION

The combustion of fuel to produce either useful heat or electric power is the largest source of air pollution in Canada. Inventories of this pollution have been prepared since 1966 following a period when dramatic changes occurred in fuel consumption trends.[1, 2] These trends have been derived from fuel consumption data provided by W.R. Flenniken, Mineral Resources Division, EMR, and are used as a basis for projecting fuel consumption to the year 1980.

The impact of this projection on the air environment will depend largely upon the selection of pollution abatement measures. Therefore, this study was undertaken to illustrate the extent to which the deterioration of the environment may be prevented by applying technically feasible, advanced fuel and combustion technology.

FACTORS AFFECTING FUEL CONSUMPTION TRENDS

Fuel Manipulation

Fuel consumption trends during the past two decades have been influenced not only by fuel cost but by the cost of fuel use, that is, capital cost, maintenance and labour. However, another significant parameter of present trends is the pollution potential of conventional fuels. One fuel produces more pollution than another because of a higher carbon:hydrogen ratio and higher ash content. To illustrate this, Table 1 gives computations of pollution produced by coal, oil, and natural gas when burned in the smallest and in the largest combustion systems - for residential heating and industry respectively. These computations take into account both fuel properties and the more advanced combustion technology for oil and gas than for coal in applications other than thermal power generation. In our free enterprise environment, this relative pollution potential of conventional fuels has led to fuel use manipulation to meet increasingly stringent pollution abatement regulations.

At first, coal was replaced by oil. When natural gas became available to a large part of Canada's population, it made important strides in replacing both coal and oil in their traditional markets and in capturing new fuel markets. Were it not for this trend, our urban communities would be suffering considerably more visual and odorous air pollution today than they do. An example of actual pollution abatement by manipulating fuels for residential heating is given in Table 2, where it is shown that conversion from coal to oil resulted in a fuel cost saving of 21% and a pollution emission reduction of 46%. Further improvements are shown for an oil "blue flame", which is an advanced technology, and for natural gas.

This trend has virtually excluded coal from all of its former markets except power generation and coke production for blast furnaces. In the case of thermal power generation, the high costs of large and efficient combustion processes, gas cleaning equipment, and tall stacks can be justified by low fuel cost. This is fortunate because power generation provides a large bulk market for coal and its use for this purpose conserves the more limited oil and natural gas resources for the small combustion systems which, of necessity, emit their pollution close to ground level.

Equipment Replacement

The exclusion of coal from its traditional markets means that coal-burning furnaces of an earlier era have now been scrapped and have been replaced by oil/gas-fired furnaces. In this process of "fuel conversion" a return on capital investment has been realized through lower operating and maintenance costs (and sometimes lower fuel cost) so that fuel manipulation has been profitable. Conversely, should supplies of natural gas and oil become short, reverting to the use of coal will be expensive. In considering such a possibility beyond 1980, it should be kept in mind now that with the exception of mineral processing and smelting, today's oil/gas-fired furnaces cannot be converted to coal firing and the cost of replacing them with coal-burning furnaces would be a severe national economic burden. This fact alone strongly supports the suggestion to plan on producing a high-calorific-value, low-sulphur, gaseous fuel from coal when a substitute for natural gas is required in the future. In doing so, the air pollution burden will be kept low, according to standards now in force, which otherwise might not be possible unless there were substantial break-throughs in the technology of firing raw coal in small combustion systems. The most likely proposition for using raw coal to serve the small fuel user is to erect large central steam stations and to distribute heat; however, experience has been that such a proposition suffers large heat-energy losses in relation to the size of the distribution system. These losses are avoided by distributing oil and gas instead of heat.

Definition of "Abatement Measures"

In the following pages reference is frequently made to "abatement measures". Use of this term stems from the realization that the pollution damage which has been done by technology can be undone by applying both more and new technology. The term "abatement measures" is meant to include any technology which is not now generally applied to a given process but which may be applied to protect the environment.

Abatement Measures to Be Taken

In order to project the pollution burden from fuel combustion in 1980, the abatement measures must be anticipated. For this paper it is assumed that abatement measures will be taken to assist the most people, most of the time - those who are concentrated in urban communities.

The automobile is the largest source of harmful pollution, as shown in Table 8. Therefore, abatement measures to reduce this source of pollution would seem to warrant the highest priority. Actually, control measures are being enforced gradually in the United States and, already, a beneficial effect is being felt in Canada through close ties with the automobile industry in the United States.

With the continued displacement of coal by residual oil in the commercial and industrial markets, the next priority abatement measure is the desulphurization of residual oil.

The next priority is to reduce the emissions of oxides of nitrogen. The first step will be to apply low-excess-air burners in industry as explained later.

The next priority is to apply 1970 technology to processes such as steel mills and mineral processes where electrostatic precipitators and bag filters are being installed to collect at least 0.1 million tons more of dust in 1980 than in 1970.

These and other assumptions regarding abatement measures are explained in Appendix 1, items 2 to 12 inclusive.

Assumptions for Projecting to 1980

Even if the foregoing assumptions prove to be correct, projecting the air pollution burden to 1980 is fraught with many uncertainties. In general terms, it seems prudent to assume that trends established between 1965 and 1970 will continue to 1980 but with certain alterations that seem inevitable.

(a) Non-Leaded Gasoline and Automobile Emissions

One of the most interesting, and inevitable, changes will be to motor gasoline as a result of automobile pollution abatement regulations originating in the United States. These regulations require significant reductions in emissions of hydrocarbons, carbon monoxide, and nitrogen oxides. To meet these regulations, alterations to the automobile engine are being made which will, in turn, require the removal of tetraethyl lead from gasoline because it blocks recirculation jets needed to reduce nitrogen oxide emission and it poisons catalytic mufflers. In the United States, 65% of the total effort required to convert fully to a three-grade gasoline system with gradual removal of lead has already been made or committed.(3) In this system, regular and premium gasolines retain a maximum of 3.0 g/gal* of lead. A new gasoline is added which has a 93 Research octane number or 85 Motor octane number and which will contain a maximum of 0.5 g/gal lead through 1973 but will contain no lead in 1974.(3)

In Canada, one oil company is presently marketing unleaded gasoline and two are marketing low-lead gasoline, and it is understood that the entire industry anticipates that the removal of lead is inevitable. Although refinery streams can be altered at any time, to do so quickly will result in high refinery costs and, possibly in some minor interruptions in retail marketing. Therefore, the industry seems to prefer changing streams in the period of 1974 to 1975.

Until the United States officially declares a final strategy for lead removal, it seems reasonable to anticipate a gradual removal of lead in Canada and the widespread use of unleaded gasoline after 1975. This is a factor in projecting gasoline consumption to the year 1980 because the efficiencies of 1970 or similar engines with unleaded gasoline will be reduced by 12%. An offsetting factor is the established trend to small automobiles, which may be accelerated by high gasoline costs resulting from higher refinery costs to produce the unleaded fuel. In the United States, the increased cost has been calculated to be 15% to 16% compared with its 1970 cost.(3) Therefore, in estimating the gasoline consumption for the year 1980, it was assumed that, (1) engine efficiency will be reduced by 12% (increased

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*g/gal. = grams per U.S. gallon.

unleaded fuel consumption per hp hr), (2) overall fuel consumption will be reduced 20% due to the small-car trend, and (3) Canadian population growth will continue at the rate of 2.5% per annum.

(b) Desulphurization of Residual Fuel Oil

For this study, it was assumed that the sulphur content of residual oil will be reduced either from 2.5% to 0.5% or by 2.0% by 1975.

(c) Low-Excess-Air Combustion

For this study it was assumed that low-excess-air combustion will be applied to 50% of industrial coal, oil, and gas with a resulting reduction of 25% of NO emissions by 1980. Involved are several individual technologies which may be selected in suitable combinations for a particular fuel.

FUEL CONSUMPTION AND POLLUTION EMISSIONS

The total fuel consumption projected to 1980 and the resulting air pollution, if abatement measures be taken, are summarized in Table 3. Shown is a reduction in 1980 of 33% below the 1970 pollution burden. However, whether this reduction in total pollution will be accurately reflected by an improvement in air quality depends on fuel selection trends.

The overall fuel consumption trends were examined as shown in Table 4 as well as the pollution from the individual fuels as shown in Tables 5 to 7 inclusive. The distribution of fuels by use category and corresponding pollution are given in Table 8.

In analysing these tables it should be pointed out that abatement measures will considerably reduce the gaseous pollutants, namely SO_2, SO_3, CO, and oxides of nitrogen from all combustion processes as well as most of the hydrocarbons from automobiles. The particulates from burning coal and residual oil and from the odorous exhaust of diesel engines will continue to increase in pace with the respective fuel consumptions. Therefore, the air will remain dirty and odorous in certain areas.

A final projection of electric power generation in Canada to 1980 was not published at the time of writing and only preliminary information was available as shown in Table 9. Corresponding fuel consumption for thermal generation is given in Table 10 and the resulting pollution is given in Table 11.

A recapitulation of the reduction of harmful pollution is given in Table 12 to illustrate the positive effect of applying abatement measures. Thus, it appears to be technically feasible to expect a net reduction of 6.9 million tons of fuel combustion pollution in Canada in 1980. The amount actually eliminated will depend largely on the state of repair of automobile engines.

However, the particulate pollution from industrial coal (including coke production) and from residual oil combustion will increase from 0.18 million tons in 1970 to 0.40 million tons in 1980. This is a 122% increase above the 1970 level. Offsetting this is a reduction of 0.1 million tons of particulates from steel mills and metallurgical processes in which new electrostatic precipitators are being installed.

POLLUTION BURDEN OF AIR SHEDS

Little is known about the dispersion and assimilative capacity of air sheds. Therefore, it is difficult to anticipate what impact the foregoing pollution will have on the air environment in 1980.

In order to develop a mental model of air shed pollution burden, an elementary computation was undertaken by Dr. H. Whaley, Canadian Combustion Research Laboratory (CCRL). In this model, the pollution burden in lb/10^8 lb air was calculated for a static air shed of a given capacity with no allowance for either transboundary flow or natural scavenging. The air shed total volume and air weight capacities are given in Table 13.

For this study, the height of the air sheds was varied to assimilate the influence of atmospheric mixing height on pollution burden as shown in Table 14. CCRL research on atmospheric dispersion indicates that in a dynamic situation, pollutant concentrations 16 km downwind from a large industrial source would be reduced by a dilution factor up to 3200; however, it is clear that much work still remains to be done both on bulk movement of pollutants over long distances and on the capability of static and dynamic air sheds to reduce pollution levels.

None-the-less, in the knowledge of fuel combustion pollution emission trends, the data in Table 14 indicate a significant improvement in 1980 of the air quality for the urban communities which were selected for study. However, a similar model study in the vicinity of large coal-fired thermal power stations would be the reverse. There is a serious risk, therefore, that this will have the effect in central Canada of producing a dirtier air environment even though the total pollution burden may be reduced.

This leads to a final observation that the 1970 level of air pollution will return in the year 2004 but, by that time, advanced technology will likely be applied on a massive scale to such as nuclear power and new, non-polluting transportation systems.

COST OF ABATEMENT MEASURES

The cost of applying "abatement measures" is difficult to evaluate. Prof. Courtright, Queen's University, made a useful study[4] which is the basis for Table 15. Though these estimated costs cannot be defended, they indicate the magnitude of capital investments that are necessary in the next few years if our air environment is to be made healthier. One difficulty in preparing Table 15 was that cost of fuel combustion abatement technology could not be separated from process abatement technology; therefore both were included in the projected $1.6-billion, industrial-capital expenditure between 1970 and 1980.

SUMMARY

The high cost of reducing gaseous pollution and the prospects of increasing particulate pollution in Central Canada during the next decade are conflicting trends which could be the objects of legislative actions by environmental-control authorities. The high cost of corrective measures cannot be prevented but the dustier air can be restricted by (1) locating new coal-fired thermal generating stations at long distance from load centres and equiping them with properly designed stacks, (2) reducing thermal electric generation, and (3) providing for low-sulphur fuel oil to displace coal in Central Canada until nuclear power is available on a large scale.

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3. Anonymous, "Lead Removal From Gasoline - Economic Impact", Summary of a Study by Bonner & Moore Associates, Inc., under contract with the Environmental Protection Agency, U.S.A., September 1971.

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Table 1

Pollutants Produced by Present Generation of Burners*

lb pollutant/10^6 Btu

	Domestic Heating			Commercial-Industrial Applications		
	Anthracite	No. 2 Oil	Nat. Gas	U.S. Bituminous Coal (PF) (3% S)	No. 6 Oil (2.5% S)	Nat. Gas
CO_2	233.54	160.65	118.8	228.8576	166.3176	118.8
NO	0.1448 (150 ppm 140% TA)	0.0656 (75 ppm 120% TA)	0.0397 (52 ppm 110% TA)	0.4627 (450 ppm 120% TA)	0.3905 (450 ppm 120% TA)	0.1719 (225 ppm 110% TA)
CO	0.1350	0.0820 (100 ppm)	0.07132 (100 ppm)	0.0960 (100 ppm)	0.08099 (100 ppm)	0.07132 (100 ppm)
Particulates	0.3745 (1.0% wt)	0.1280 (0.25% wt)	-	0.2387 (0.315% wt)	0.1323 (0.25% wt)	-
SO_2	1.0490	0.7000	-	1.6934	2.6450	-
SO_3	0.0260	.0140	-	0.0423	0.06613	-
Total lb/10^6 Btu	234.7293	161.6396	118.911	231.3907	169.6325	119.04322
Harmful lb/10^6 Btu	1.7293	0.9896	0.11102	2.5331	3.3149	0.24322
Harmful excluding SO_x	0.6543	0.2756	0.11102	0.7974	0.6038	0.24322

*Most of these data are judgement averages for typical combustion conditions.

TABLE 2

Air Pollution Comparison - 1946-1969

Heating of a Selected Residence[1/]

(based on reliable fuel data)

	Fuel Consumption Btu x 10^6	Air Pollution lb		% change for 1946-1969 Fuel Consumption	Air Pollution	
		Incl. CO_2	Harmful		Incl. CO_2	Harmful
1946 5 tons anthracite (5-yr av)	133.5	31,336	230.86	Base[2/]	Base	Base
1969 633.5 IG No. 2 Furnace Oil (5-yr av)	105.161	16,998	104.07	-21.2%[3/]	-46%	-55%
1969 Natural gas Consumption Estimated	100.0	11,891	11.10	-25%[3/]	-62%	-95%
1976 Forecast Blue Flame Burning No. 2 Furnace Oil	100.0	16,139	95.38	-25%[3/]	-48%	-59%

[1/] Residence of the Author - 2-storey, 3-bedroom, 26 x 25 ft (1,300 sq ft)

[2/] The unavoidable overfiring with coal caused overheating of the premises, thereby increasing fuel wastage and pollutant emission.

[3/] This reflects both improved combustion efficiency and improved process control.

TABLE 3

TOTAL FUEL CONSUMPTION AND HARMFUL AIR POLLUTION 1965 to 1980

Based on Abatement Measures

		Fuel Consumption		Air Pollution*	
		Btu x 10^{12}	% total	lb x 10^{6}	% total
Coal	(1965)	557.3	17.9	1295.57	2.4
	(1970)	625.9	14.9	1704.82	7.1
	(1980)	917.5	11.6	3233.04	20.2
Petroleum Products	(1965)	1954.9	62.8	53470.62	97.4
	(1970)	2561.8	61.2	21967.78	92.0
	(1980)	4396.5	55.7	12297.31	76.9
Gas (including Propane)	(1965)	601.2	19.3	119.63	0.2
	(1970)	1000.2	23.9	208.08	0.9
	(1980)	2578.7	32.7	465.93	2.9
TOTAL	(1965)	3113.4	100.0	54885.80	100.0
	(1970)	4187.8	100.0	23880.70	100.0
	(1980)	7892.8	100.0	15996.29	100.0

*Does not include CO_2.

TABLE 4

FUEL CONSUMPTION BY TYPES - 1965 to 1980

Fuel Type		Fuel in Standard Units	Btu x 10^{12}	% per annum increase
Coal (short tons x 10^6)				
Canadian Bituminous	(1965)	4.978	123.62	-10.34[1/]
	(1970)	2.88	71.26	[2/]
	(1980)	1.6	39.74	-5.67
Canadian Sub-bit	(1965)	1.864	29.73	+13.43[1/]
	(1970)	3.50	55.83	+10.85[2/]
	(1980)	9.8	156.33	
Canadian Lignite	(1965)	1.796	23.94	+12.04[1/]
	(1970)	3.17	42.26	+11.13[2/]
	(1980)	9.1	121.36	
Canadian Briquettes	(1965)	.021	.50	-15.40[1/]
	(1970)	.009	.21	0
	(1980)	.009	.21	
U.S. Bituminous	(1965)	14.314	366.24	+4.04[1/]
	(1970)	17.447	446.50	+2.83[2/]
	(1980)	23.8	590.28	
U.S. Anthracite	(1965)	.502	12.77	0
	(1970)	.38	9.60	0
	(1980)	.38	9.60	
U.S. Briquettes	(1965)	.014	.4	-
	(1970)	.001	.03	-
	(1980)	0	0	

(continued next page)

TABLE 4 - (cont'd)

Fuel Type		Fuel in Standard Units	Btu x 10^{12}	% per annum increase
Petroleum Products (bbl x 10^3)				
Light oil	(1965)	79147	461.48	+5.12[1/]
	(1970)	101591	592.38	+5.12[2/]
	(1980)	167382	976.00	
Kerosene & Stove Oil	(1965)	18818	107.38	+0.27[1/]
	(1970)	19074	108.85	+0.27[2/]
	(1980)	19595	111.83	
Diesel Oil	(1965)	35641	209.55	+5.83[1/]
	(1970)	47313	278.18	+5.83[2/]
	(1980)	83381	490.25	
Heavy Oil	(1965)	78175	497.01	+7.04[1/]
	(1970)	109851	698.41	+7.04[2/]
	(1980)	216903	1379.02	
Crude Oil	(1965)	288.1	1.6	+5.08[1/]
	(1970)	366.7	2.05	+42.31[2/]
	(1980)	12500.0	69.84	
Auto Gasoline	(1965)	128542.5	670.72	+5.41[1/]
	(1970)	167314.0	873.02	+4.50[2/]
	(1980)	259833.5	1355.78	
Aircraft Gasoline	(1965)	1206.9	7.15	+4.5[1/]
	(1970)	1506.1	8.91	+4.5[2/]
	(1980)	2335.0	13.83	
Gas Fuels (MMcf)				
Natural Gas	(1965)	573016.2	577.028	+10.11[1/]
	(1970)	917440.9	933.86	+10.10[2/]
	(1980)	2482215.4	2446.09	
Propane (bbl x 10^3)	(1965)	6321.0	24.20	+22.33[1/]
	(1970)	17314.6	66.30	+7.18[2/]
	(1980)	34629.0	132.60	
TOTAL	(1965)		3113.39	+6.11[1/]
	(1970)		4187.81	+6.54[2/]
	(1980)		7892.76	

1/ % per annum increase from 1965 to 1970.

2/ % per annum increase from 1970 to 1980.

TABLE 5

COAL CONSUMPTION AND AIR POLLUTION
1965-1980

	Fuel Consumed Btu x 10^{12}	Harmful[1/] Pollution lb x 10^6
Residential and Commercial Heating		
1965	47.110	104.199
Rate of Increase to 1970, % per annum	-29.3	-29.3
1970	8.272	18.389
Rate of Increase from 1970 to 1980, % per annum		
1980	nil	nil
Industrial		
1965	359.520	805.499
Rate of Increase to 1970, % per annum	2.7	7.6[3/]
1970	411.736	1159.161
Rate of Increase from 1970 to 1980(a) % per annum	5.3	8.6[3/]
1980 (a) (Using abatement measures)[2/]	692.885	2650.559
Rate of Increase from 1970 to 1980(b), % per annum	5.3	9.0[3/]
1980 (b) (Using 1970 Technology)	692.785	2744.866
Coke Making		
1965	150.670	385.881
Rate of Increase to 1970, % per annum	6.4	6.4
1970	205.871	527.271
Rate of Increase from 1970 to 1980(b), % per annum	0.9	1.0
1980 (b) (Using 1970 Technology)	224.655	582.480

1/ This does not include CO_2 but does include coke, iron, and steel process dust.

2/ Abatement measure for coal use is low-excess-air combustion of pulverized coal applied to 50% of industrial flames to reduce NO pollution by 25%.

3/ Pollution increases at a faster rate than fuel consumption in Btu x 10^{12}, because of a higher percentage of high-ash lignite and sub-bituminous coal in the mix which makes up the total.

TABLE 6

OIL CONSUMPTION AND AIR POLLUTION
1965-1980

	Fuel Consumption Btu x 10^{12}	Harmful[1/] Pollution lb x 10^{6}
Residential and Commercial Heating		
1965	521.720	497.019
Rate of Increase to 1970, % per annum	4.6	4.6
1970	652.172	623.309
Rate of Increase from 1970 to 1980(b), % per annum	4.8	2.6
1980 (b) (Using 1970 Technology)[2/].............	1037.458	804.640
Automobile Gasoline		
1965	670.718	50584.120
Rate of Increase to 1970, % per annum	5.4	-18.6
1970	873.021	18080.303
Rate of Increase from 1970 to 1980(a), % per annum	4.5	-7.29
1980 (a) (Using abatement measures)[3/]	1355.78	8484.113
Rate of increase from 1970 to 1980(b), % per annum	-	0.37
1980 (b) (Using 1970 Technology)	1193.084	18754.275[5/]
Aircraft Gasoline and Jet Fuel[4/]		
1965	54.292	325.701
Rate of Increase to 1970, % per annum	0.87	4.0
1970	56.694	395.295
Rate of Increase from 1970 to 1980(b), % per annum	1.1	4.2
1980 (b) (Using 1970 Technology)	62.917	599.372

[1/] This does not include CO_2.

[2/] With sulphur content reduced 0.2% below 1970 level.

[3/] To project automobile pollution it was assumed that automobile performance will meet the emission regulations published by the U.S. authorities during the summer of 1971.

[4/] There are no statistical data available on jet fuel consumption. For this study it has been assumed that 50% of kerosene and stove oil consumed in 1965 was jet fuel and this has been used as a basis for projecting to 1980, admittedly a rough estimate.

[5/] This reflects the influence of automobile pollution abatement measures taken between 1968 and 1970 model years.

(continued next page)

TABLE 6 - (cont'd)

OIL CONSUMPTION AND AIR POLLUTION
1965-1980

	Fuel Consumption Btu x 10^{12}	Harmful[1/] Pollution lb x 10^{6}
Diesel Fuel		
1965	209.550	400.705
Rate of Increase to 1970, % per annum	5.8	5.8
1970	278.180	531.925
Rate of Increase from 1970 to 1980(b), % per annum	5.8	5.3
1980 (b) (Using 1970 Technology)[6/]	490.200	887.872
Industrial		
1965	498.610	1664.410
Rate of Increase to 1970, % per annum	7.1	7.1
1970	701.733	2336.942
Rate of Increase from 1970 to 1980(a), % per annum	7.5	-4.22
1980 (a) (Using abatement measures)	1450.133	1522.033
Rate of Increase from 1970 to 1980(b), % per annum	7.6	7.6
1980 (b) (Using 1970 Technology)	1450.133	4929.122
Total Petroleum Fuels		
1965	1954.890	53471.955
Rate of Increase to 1970, % per annum	5.6	-16.3
1970	2561.800	21967.777
Rate of Increase from 1970 to 1980, % per annum	5.5	-5.6
1980 (a) (Using abatement measures)	4396.485	12297.31
Rate of Increase from 1970 to 1980(b), % per annum	5.2	1.7
1980 (b) (Using 1970 Technology)	4233.792	25975.281

[6/] With sulphur content of diesel fuel reduced 0.1% below 1970 level.

TABLE 7

NATURAL GAS AND PROPANE CONSUMPTION AND AIR POLLUTION
1965-1980

	Btu x 10^{12}	Harmful[1/] Pollution lb x 10^6
Residential and Commercial		
1965	314.264	48.287
Rate of Increase to 1970, % per annum	9.6	12.9
1970	497.232	88.553
Rate of Increase from 1970 to 1980(b), % per annum	9.0	10.1
1980 (b) (Using 1970 Technology)	1174.634	231.696
Industrial		
1965	286.662	69.722
Rate of Increase to 1970, % per annum	11.5	11.5
1970	492.930	119.530
Rate of Increase from 1970 to 1980, % per annum	11.0	7.0
1980 (a) (Using abatement measures)[2/]	1404.062	234.227
1980 (b) (Using 1970 Technology)	1404.062	341.491
Total Natural Gas and Propane Fuels		
1965	601.231	118.009
Rate of Increase to 1970, % per annum	10.5	12.0
1970	1000.162	208.083
Rate of Increase from 1970 to 1980, % per annum	10.0	8.4
1980 (a) Using abatement measures	2578.696	465.923
Rate of Increase from 1970 to 1980(b), % per annum	-	10.7
1980 (b) (Using 1970 Technology)	2578.690	573.187

[1/] Does not include CO_2.

[2/] Abatement measure for industrial natural gas use is low excess-air combustion applied to 50% of industrial flames to reduce NO pollution by 25%.

TABLE 8

FUEL CONSUMPTION BY USE CATEGORY AND AIR POLLUTION
1965-1980

	Fuel Consumption Btu x 10^{12}	Harmful Pollution[1/] lb x 10^6	Harmful Pollution[1/] % of Total Annual
Residential and Commercial			
Heating			
1965	882.784	652.095	1.2
Rate of Increase to 1970, % per annum	5.6	2.3	
1970	1157.676	730.251	3.1
Rate of Increase from 1970 to 1980, % per annum	6.7	3.6	
1980 (b) (Using 1970 Technology)	2211.691	1036.336	6.5
Transportation[2/]			
1965	934.560	51310.526	93.5 (Auto 92.2)
Rate of Increase to 1970, % per annum	5.3	-18.5	
1970	1207.895	18475.598	79.2 (Auto 77.4)
Rate of Increase from 1970 to 1980, % per annum	4.7	-6.0	
1980 (a) (Using abatement measures for the automobile only)	1908.94[3/]	9950.049	62.2 (Auto 53.0)
Rate of Increase from 1970 to 1980(b), % per annum	-	0.93	
1980 (b) (Using 1970 Technology)	1679.87	20271.591	——
Industrial			
1965	1295.412	2924.546	5.3
Rate of Increase to 1970, % per annum	6.9	7.2	
1970	1812.270	4142.904	17.7
Rate of Increase from 1970 to 1980(a), % per annum	7.6	2.0	
1980 (a) (Using abatement measures)	3771.635	5009.924	31.3
Rate of Increase from 1970 to 1980(b), % per annum	7.6	7.5	
1980 (b) (Using 1970 Technology)	3771.635	8567.889	——

[1/] This does not include CO_2.

[2/] It is assumed that application of advanced technology to gasoline and automobile emissions is in progress and will be completed by 1976 model year according to standards published by U.S. authorities in the summer of 1971. Diesel fuel is included and is in addition to gasoline and jet fuel, Table 6.

[3/] This reflects a 12% reduction in engine efficiency because of using unleaded gasoline.

TABLE 9

ELECTRIC POWER GENERATION IN CANADA[1/]

net Generation in 10^9 KWh

	Coal	Oil	Gas	Hydro	Nuclear	Total
1965	15.7	2.6	4.8	87.7	.12	110.9
1970	31.2	5.5	5.5	128.5	1.0	171.7
1980	60.0 (71)[2/]	31.5 (27)[2/]	20.2 (18)[2/]	207.0	35.1	353.8

TABLE 10

FUEL CONSUMPTION FOR THERMAL ELECTRIC GENERATION IN CANADA [1/]

	Coal x 10^6 tons	Oil x 10^6 bbl	Gas x 10^9 cf	Thermal Generation 10^9 KWh
1965	7.73	5.4	59.6	23.1
1970	15.3	10.7	70.8	42.2
1980	35.5[3/]	55.5	228	111.7 (116)[2/]

[1/] Preliminary data recorded during conversations with E. Bell, National Energy Board.

[2/] These data would appear to more closely match projected fuel consumption.

[3/] Coal projection by Energy Sector, EMR.

TABLE 11

THERMAL POWER GENERATION AND AIR POLLUTION
1965 to 1980

	Total Fuel Input Btu x 10^{12} [2]	Total Pollution lb x 10^6 [3]	Net Generation 10^9 kWh	Average Heat Rate Btu/kWh
1965	261.382	441.946	23.1	11,313
Rate of Increase to 1970 % per annum	12.31	5.37	12.81	-
1970	466.989	574.132	42.2	11,119
Rate of Increase from 1970 to 1980 (a) % per annum	10.54	17.49	10.22	-
1980 (a) (Using Abatement Measures)[1]...	1271.786	2876.338	111.7(116)[4]	11,386(10,963)[4]
Rate of Increase from 1970 to 1980 (b) % per annum	10.54	20.39	10.22	-
1980 (b) 1970 Technology	1271.786	3671.500	111.7(116)[4]	11,386(10,963)[4]

[1] (a) Residual oil desulphurized to 0.5% after 1975
(b) 50% of coal, oil, and natural gas will be burned in low-excess-air turbulent-diffusion flames to reduce overall NO emissions by 25%.

[2] Total fuel input includes coal, oil, and natural gas fuels in quantities shown in Table 10 which was assembled almost entirely from information provided verbally by the National Energy Board except for coal quantities. Coal tonnages used in this study were supplied at a meeting of the EMR Environmental Committee on October 25, 1971.

[3] Total pollution does not include CO_2.

[4] The numbers in brackets represent more realistic coal and oil conversion to electric power.

TABLE 12

REDUCTION OF AIR POLLUTION IN 1980
BY APPLYING ABATEMENT MEASURES

	Pollution - lb x 10^6		
	By 1970 Technology Standards	By Advanced Technology Standards[1/]	Reduction
Industrial Pollutants Affected[2/]			
(Fuel Oil) SO_2 [2a/]	4426.924	1285.013	3141.911
(Fuel Oil) SO_3 [2a/]	111.244	32.361	70.883
(Coal, Oil & Gas) NO[2b/]	1552.319	1212.128	340.191
Particulates will increase as fuel use increases	-	-	-
Transportation[3/]			
(all pollutants)	20271.591	9950.049	10321.542
Total Pollution[4/]			
All Fuel Uses (net)	29878.818	15996.290	13882.528

1/ Abatement measures are considered to be limited to industrial fuels and automobile gasoline between 1970 and 1980. It is possible by 1975 that an oil "blue flame" will be in commercial use for space heating, though its impact may not be felt until after 1980.

2/ Abatement measures relating to industrial fuel use is considered to be:
(a) desulphurization of residual oil from 2.5% to 0.5% sulphur (or removal of 2%), and no sulphur removal from coal included,

(b) the application of low-excess-air burners to the burning of 50% of industrial coal, oil, and gas.

3/ Abatement measures as applied to gasoline means (a) unleaded fuel, and (b) engine CO, NO_2 and HC emissions reduced according to the limits published by the United States during the summer of 1971.

4/ There may be additional reductions of particulate and SO_2 emissions from smelting and chemical processes amounting to possibly 220 x 10^6 lb particulates and 4,800 x 10^6 lb of SO_2, by rough estimate, in 1980.

TABLE 13

CANADA AIR ENVIRONMENT DATA

	Canada	Industrial Region North of Great Lakes	Toronto	Montreal
Total area - sq mi	3,851,809	100,000	240	180
Total air volume cu ft (static)	3756.8×10^{15}	97.57×10^{15}	0.23×10^{15}	0.175×10^{15}
Total air weight - lb*	159.7×10^{15}	4.147×10^{15}	0.0010×10^{15}	0.0008×10^{15}
Dilution Factor (conservative assumption from plume dispersion research data)		3200 in less than 16 km	3200 in less than 16 km	3200 in less than 16 km

*Obtained by integrating pressure-height (temperature) relationship from ground level to the 30,000-ft elevation.

TABLE 14

POLLUTION BURDEN OF CANADIAN AIR SHEDS
FROM FUEL COMBUSTION (CALCULATED)
ASSUMING ABATEMENT MEASURES

		Canada	Industrial Region North of Great Lakes	Toronto	Montreal
Total Air Pollution (not including CO_2) lb x 10^6	(1965)	54885.8	32933.9	-	-
	(1970)	23878.9	14327.2	2302.0	2227.2
	(1980)	16196.53	9717.9	1564.5	1511.1
Pollution Burden*					
(a) Static Condition					
Short tons/sq mi/day	(1965)	0.01950	0.4571	-	-
	(1970)	0.00849	0.1963	13.14	16.95
	(1980)	0.005	0.1331	8.93	11.50
(b) Static Condition					
lb/10^8 lb air/24 hr, variation with atmospheric mixing height					
2,000 ft	(1965)	.943	21.800		
	(1970)	.410	9.483	634.900	819.027
	(1980)	.278	6.433	431.732	556.938
4,000 ft	(1965)	.485	11.223		
	(1970)	.211	4.882	326.858	421.650
	(1980)	.143	3.312	222.263	286.722
6,000 ft	(1965)	.333	7.704		
	(1970)	.145	3.351	273.973	289.422
	(1980)	.098	2.273	186.302	196.807

(continue next page)

TABLE 14 (cont'd)

		Canada	Industrial Region North of Great Lakes	Toronto	Montreal
$lb/10^8$ lb air/24 hr, variation with atmospheric mixing height					
8,000 ft	(1965)	.257	5.948		
	(1970)	.112	2.588	173.243	223.485
	(1980)	.079	1.755	117.805	151.970
10,000 ft	(1965)	.212	4.900		
	(1970)	.092	2.130	142.686	184.066
	(1980)	.062	1.446	97.026	125.165
15,000 ft	(1965)	.152	3.510		
	(1970)	.066	1.528	102.277	131.938
	(1980)	.045	1.036	69.548	89.718
20,000 ft	(1965)	.122	2.831		
	(1970)	.053	1.231	82.440	106.348
	(1980)	.036	.835	56.059	72.317
25,000 ft	(1965)	.010	2.432		
	(1970)	.046	1.058	70.842	91.386
	(1980)	.031	.718	48.172	62.142
30,000 ft	(1965)	.094	2.176		
	(1970)	.041	.947	63.368	81.746
	(1980)	.028	.642	43.090	55.587

*Computed by Dr. H. Whaley, Canadian Combustion Research Laboratory.

TABLE 15

AIR POLLUTION COSTS

	1970	1971	1972	1973	1974	1975	1980
1. Population x 10^6*	21.377	21.681	22.053	22.408	22.775	23.154	25.210
2. Negative Damage** - $ x 10^6	1700	1735	1760	1790	1800	1850	1520
3. Positive Damage*** - $ x 10^6							
Investment							
Federal DOE	1.5	1.7	1.8	2.0	2.2	2.4	5.0
Federal Scientific	17.0	18.7	20.6	22.6	24.9	27.5	50.0
Ontario DOE	4.3	4.7	5.2	5.7	6.3	7.0	14.0
Alberta DOE	0.25	0.28	0.30	0.34	0.37	0.40	0.8
Other Provinces	0.25	0.28	0.30	0.34	0.37	0.40	0.8
Montreal Urban Community	0.75	0.82	0.90	0.99	1.1	1.2	2.4
Windsor and other Industrial Assoc.	0.25	0.28	0.30	0.34	0.37	0.4	0.8
Industrial							
Stationary	100.0	100.0	100.0	100.0	100.0	100.0	20.0
Automobiles	-	-	300.0	300.0	300.0	300.0	300.0
Unleaded gasoline	25.0	150.0	150.0	150.0	150.0	150.0	0
Low Sulphur Oil	-	-	-	-	-	200.0	0
Total Cost - National $ x 10^6	1849.3	2011.8	2339.4	2372.0	2385.0	2639.3	1913.8
Total Cost - per person ($)	86.00	93.00	106.00	106.00	105.00	114.00	76.00

* Source - Statistics Canada

** There is no source of reliable information on damage costs but a study in the United States by Messrs. Larry B. Barrett and Thomas E. Waddell published by the U.S. Department of Health Education and Welfare suggests a U.S. national average cost of $80.00 per year per capita. Although this is felt to be high for Canadian conditions where population density in urban communities is less than in the U.S.A. and less thermal power is generated by coal per capita, it is used here rather than $115 per year per Canadian urban dweller estimated by Zerbe for 1980. The Zerbe estimate seems unrealistic in view of new knowledge of air shed dilution factors and positive steps being taken to reduce fuel combustion pollution and fuel spills.

***Based on a paper by J.M. Courtright, Queen's University, entitled "The Economics of Clean Air".

APPENDIX I

Assumptions for Preparing an Inventory of Air Pollution in Canada Based on 1970 Fuel Consumption

1. All coal-fired thermal power generators are assumed to be equipped with the most efficient electrostatic precipitators which, considering the average electrical resistivity of fly ash, will allow no more than 5% of the coal ash to escape to the atmosphere on an annual average. Therefore, a 151% increase in particulate emissions in 1980 will be the result of increased coal use for power generation.

2. By 1980 coal will be completely displaced from the residential and commercial heating market.

3. Before 1980, about 5 million tons of U.S. Bituminous coal now used for power generation will be displaced with natural gas and oil.

4. Starting in 1975, desulphurization of fuel oil to 0.5% sulphur content will be on a national scale.

5. Desulphurizing residual oil will alter the electrical resistivity of particulate matter so that increased particulate emission can be expected.

6. The automobile emission regulations originating in the U.S.A., and as announced in August 1971, will have a profound effect on reducing this source of pollution in 1980.

7. Non-leaded automobile gasoline will be used universally by 1975.

8. Removing lead from automobile gasoline will result in high aromatic content and 12% reduction in fuel efficiency.

9. The small-car trend has been established and will continue, at least to the extent that it will reduce total gasoline consumption by 20% which will be offset by a 12% reduction in fuel efficiency of non-leaded gasoline.

10. To calculate 1980 automobile pollution, it was assumed that the automobile population will continue to increase at 4.5% per annum with 1 million new cars added each year, the difference being the number of old cars retired.

11. The refined-oil "blue flame" will be used for residential heating only to a limited extent up to 1980 in new housing but should have a significant effect on reducing air pollution after 1980.

.. 2

APPENDIX I

12. By 1980, 50% of large industrial combustion systems will use low excess-air to reduce NO emission.

13. Combustion computations as described in 1st Addendum to Mines Branch Information Circular IC 211 apply except that coal burned in pulverized form emits 95% of its sulphur as SO_2.

Fuel Calorific Values
Used in Computing Fuel Combustion Air Pollution

Canadian Bituminous Coal	12419 BTU/lb
Canadian Sub-bituminous	7976 BTU/lb
Canadian Lignite	6668 BTU/lb
Canadian Briquettes	11900 BTU/lb
U.S. Bituminous Coal	12796 BTU/lb
U.S. Anthracite Coal	12700 BTU/lb
U.S. Briquettes	13000 BTU/lb
Motor Gasoline	149100 BTU/IG
Kerosene	164531 BTU/IG
Light Oil	159179 BTU/IG
Heavy Oil	181642 BTU/IG
Diesel Oil	164531 BTU/IG
Crude Oil	159625 BTU/IG
Propane	2500 BTU/cu ft
Natural Gas	1007 BTU/cu ft