ACID PRECIPITATION : Trends and Projections in Precursor Pollutant Emissions in Canada and in the United States. A Comprehensive Summary.

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Current emissions - SO_2 - Canada (graph 1)

On the basis of 1974 data for area sources, 1974 data for some point sources, and 1978 data for the major point sources, total Canadian emissions of SO_2 are 5.0 million tonnes yearly. About 80% of these emissions are released by sources located east of the Manitoba-Saskatchewan border.

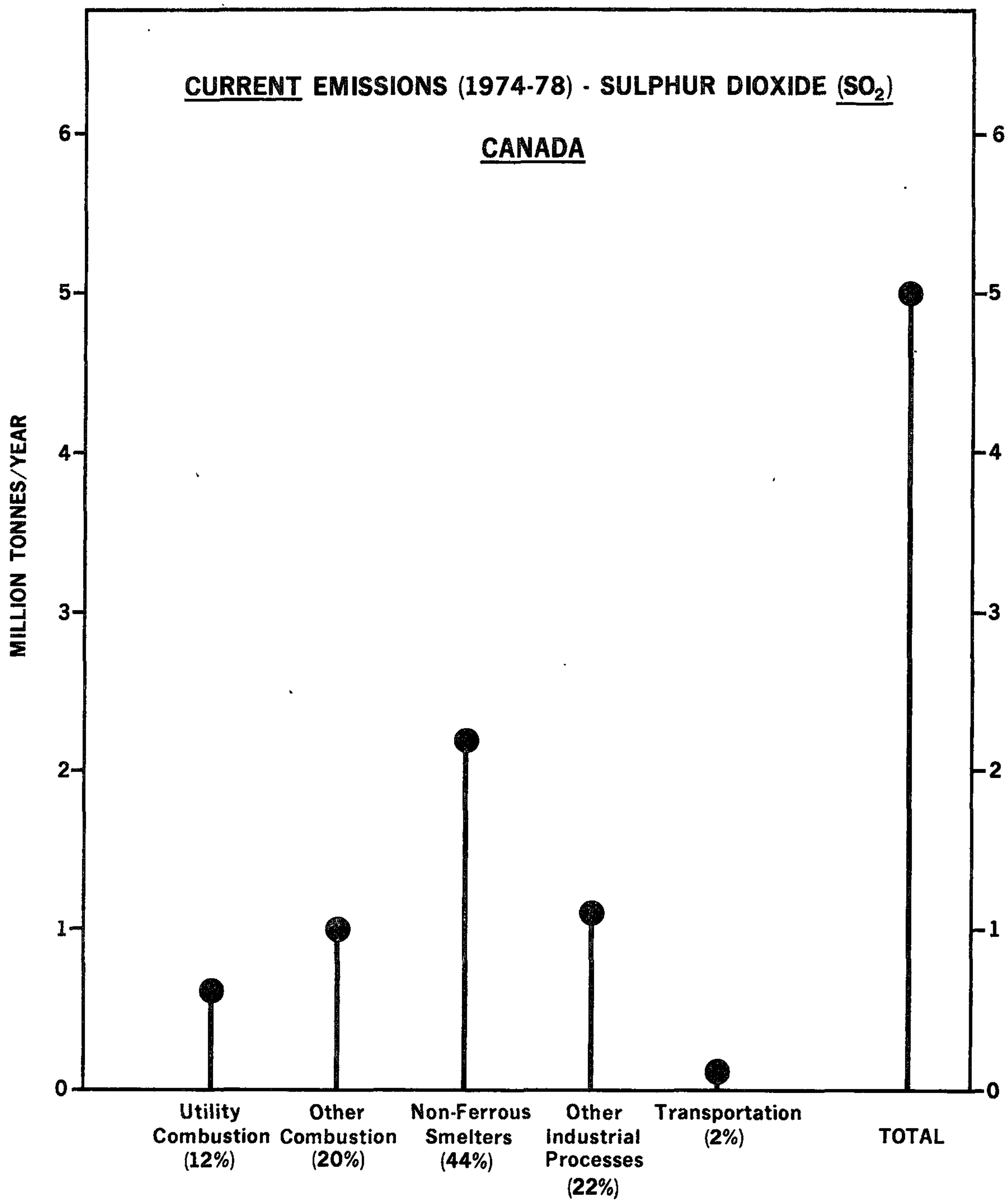
Total emissions broken down into five categories of sources indicate that non-ferrous smelters (mainly copper-nickel) contribute 44% of the total, other industrial processes (e.g. natural gas processing, petroleum refining, tar sands) about 22%, other combustion sources (residential, commercial, industrial fuel combustion) about 20%, utility combustion (mainly coal-fired power plants) close to 12%, and transportation sources (diesel-powered engines and gasoline-powered motor vehicles) about 2%.

Regionally, for provinces located in eastern Canada (west of Saskatchewan), Ontario contributes close to 43% of total Canadian emissions, Quebec - 20%, Manitoba - 11%, Nova Scotia - 4%, and New Brunswick - 3%. Ontario's rank is largely due to INCO's Copper Cliff nickel smelter complex which emits, as a single point source, roughly one million tonnes of sulphur dioxide yearly, i.e. 20% of total Canadian emissions. In Quebec's case, close to 55% of its own SO_2 emissions are due to the Noranda copper smelter complex alone, another single large point source emitter. As for Manitoba, 95% of the SO_2 emissions originating in that province are due to two non-ferrous smelters: the INCO Thompson nickel smelter and the Hudson Bay Mining and Smelting (HBMS) Copper smelter.

References: 1,2,3

Current emissions - SO_2 - United States (graph 2)

On the basis of 1973 to 1977 data for area sources, and 1977-1978 data for point sources, total United States emissions of SO_2 are 25.7 million


CURRENT EMISSIONS (1974-78) - SULPHUR DIOXIDE (SO_2)
CANADA
MILLION TONNES/YEAR
0
1
2
3
4
5
6
Utility Combustion (12%)
Other Combustion (20%)
Non-Ferrous Smelters (44%)
Other Industrial Processes (22%)
Transportation (2%)
TOTAL

tonnes yearly. About 80% of these emissions are released by sources located in states east of the Mississipi River.

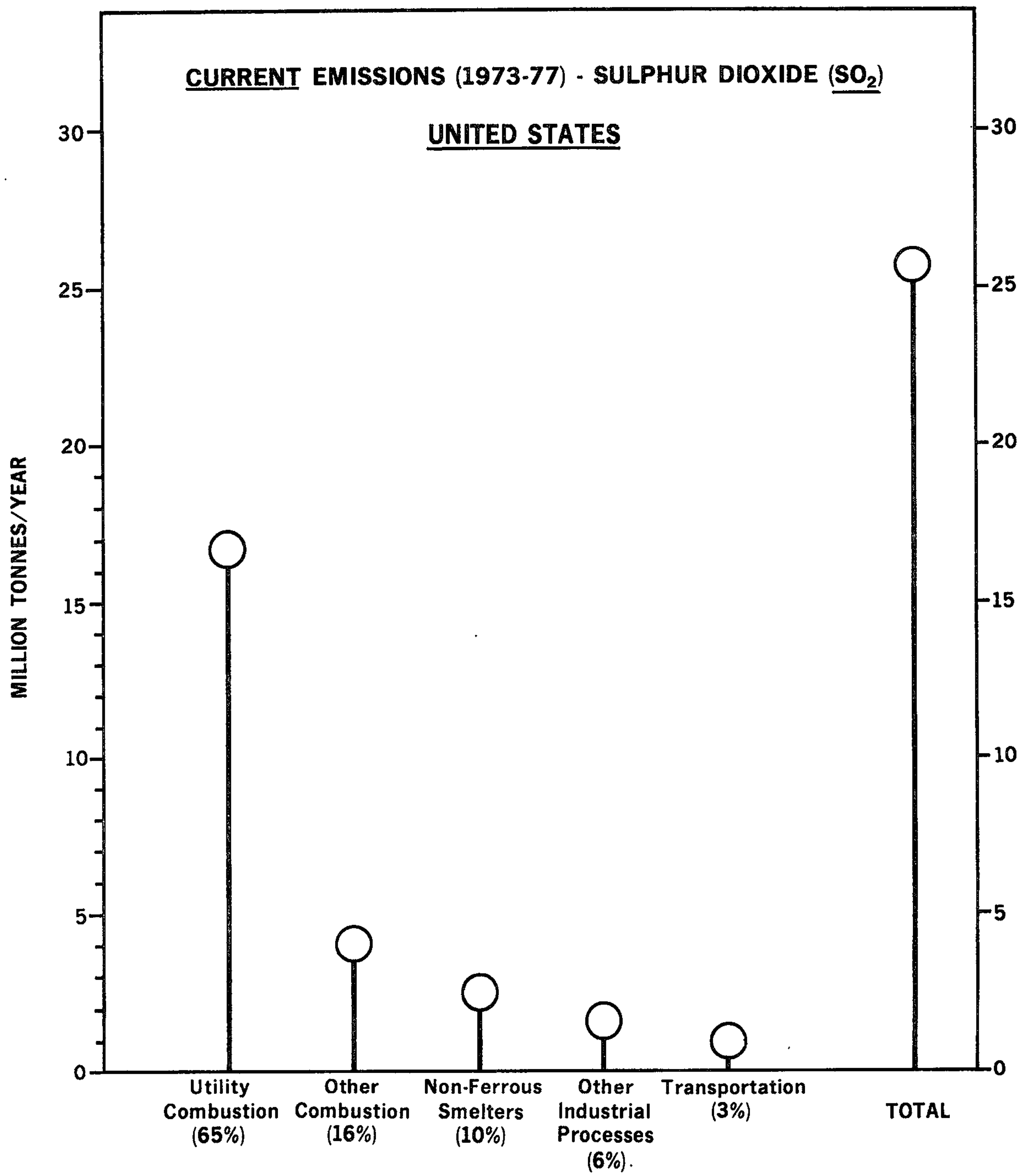
Total emissions broken down into the same five categories of sources as done for Canada (see graph 1) indicate that utility combustion (mainly coal-fired power plants) contribute close to 65% of the total, other combustion (residential, commercial, industrial fuel combustion) about 16%, non-ferrous smelters -20%, other industrial processes -6%, and transportation sources -3%.

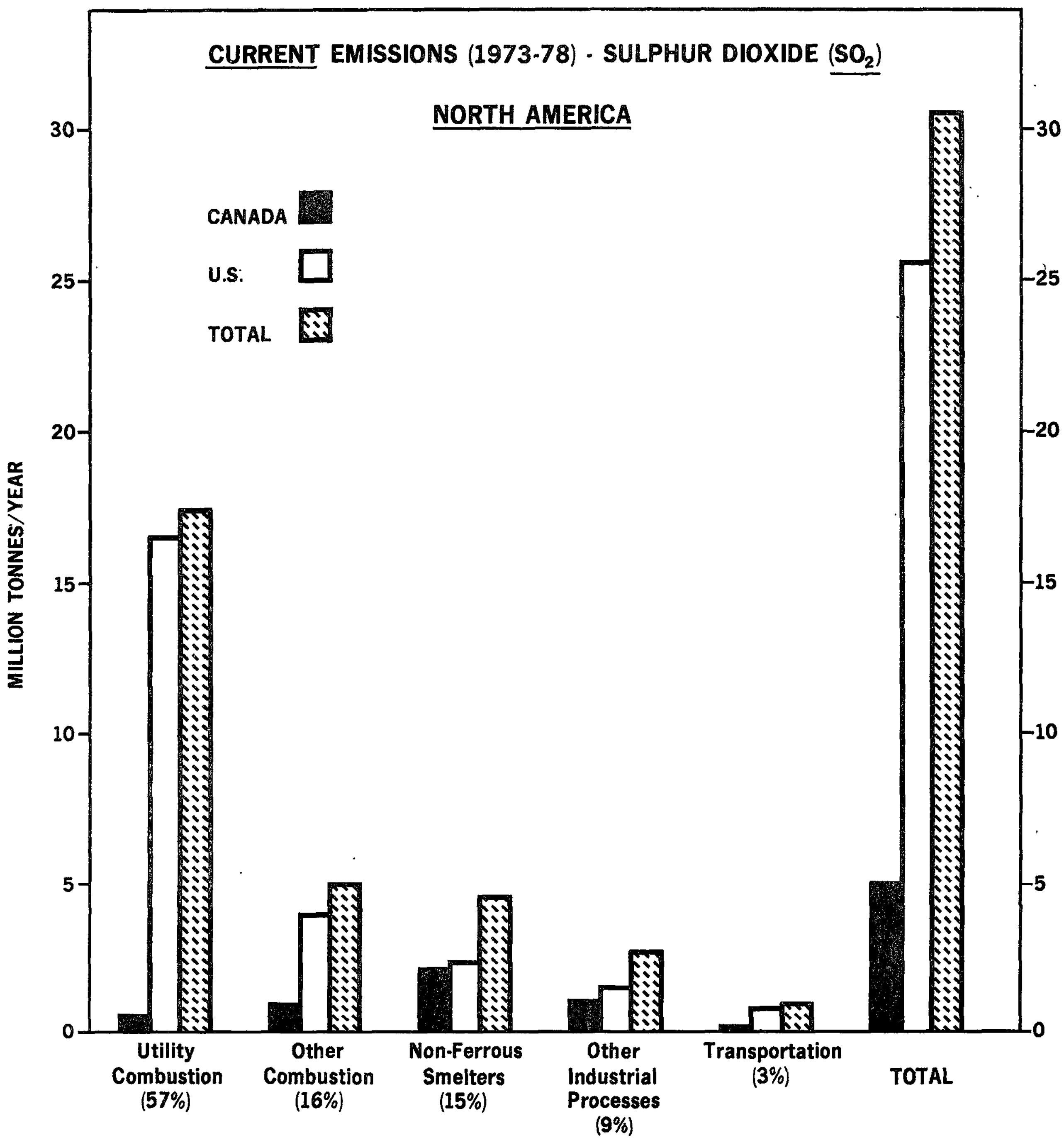
References: 1,3

Current emissions - SO_2 - North America (graph 3)

Total SO_2 emissions amount yearly to 30.7 million tonnes. The ratio of U.S. to Canadian emissions is 5 to 1 and more than half of the combined emissions come mostly from American power plants. The concern in terms of acid rain is greater here because power plants release their emissions from relatively high stacks. This enables the pollutants to be more available for transportation and transformation into acidic compounds in the higher atmosphere, and eventually for deposition on land and water surfaces at distances reaching thousands of kilometres from their original source.

The second most important category of emission sources (16% of combined U.S.-Canada emissions) is that called 'other combustion' and it includes the emissions due to residential, commercial, and industrial fuel combustion, the latter being the stronger emitter amongst these sources. On an almost equal foot are the sulphur dioxide emissions from non-ferrous smelters which reach more than 4.5 million tonnes yearly or 15% of total U.S.-Canada emissions. In an acid rain perspective these sources are however far more important than 'other combustion sources' because they are limited in


CURRENT EMISSIONS (1973-77) - SULPHUR DIOXIDE (SO_2)
UNITED STATES
MILLION TONNES/YEAR
30
25
20
15
10
5
0
Utility Combustion (65%)
Other Combustion (16%)
Non-Ferrous Smelters (10%)
Other Industrial Processes (6%)
Transportation (3%)
TOTAL


CURRENT EMISSIONS (1973-78) - SULPHUR DIOXIDE (SO_2)
NORTH AMERICA
CANADA
U.S.
TOTAL
MILLION TONNES/YEAR
0
5
10
15
20
25
30
Utility Combustion (57%)
Other Combustion (16%)
Non-Ferrous Smelters (15%)
Other Industrial Processes (9%)
Transportation (3%)
TOTAL

number, and discharge their emissions through high stacks, which makes for significant individual point sources. In the case of other combustion sources the problem is more related to numerous low-level sources of emissions spread over a wide geographical area. It is of note that Canada's most important SO_2 emitting sector (represented by the black middle bar) is dwarfed considerably by American sources of emissions.

The primary contributor to domestic SO_2 emissions is therefore different in U.S. and in Canada. In the first case (U.S.) about two-thirds of total domestic emissions come from power plants, while in the other close to one-half come from non-ferrous smelters. Even though in terms of percentages these ratios are somewhat similar (65% vs. 44%), in terms of absolute numbers they are quite different - 18.6 million tonnes of SO_2 from American power plants, 2.4 million tonnes of SO_2 from Canadian non-ferrous smelters.

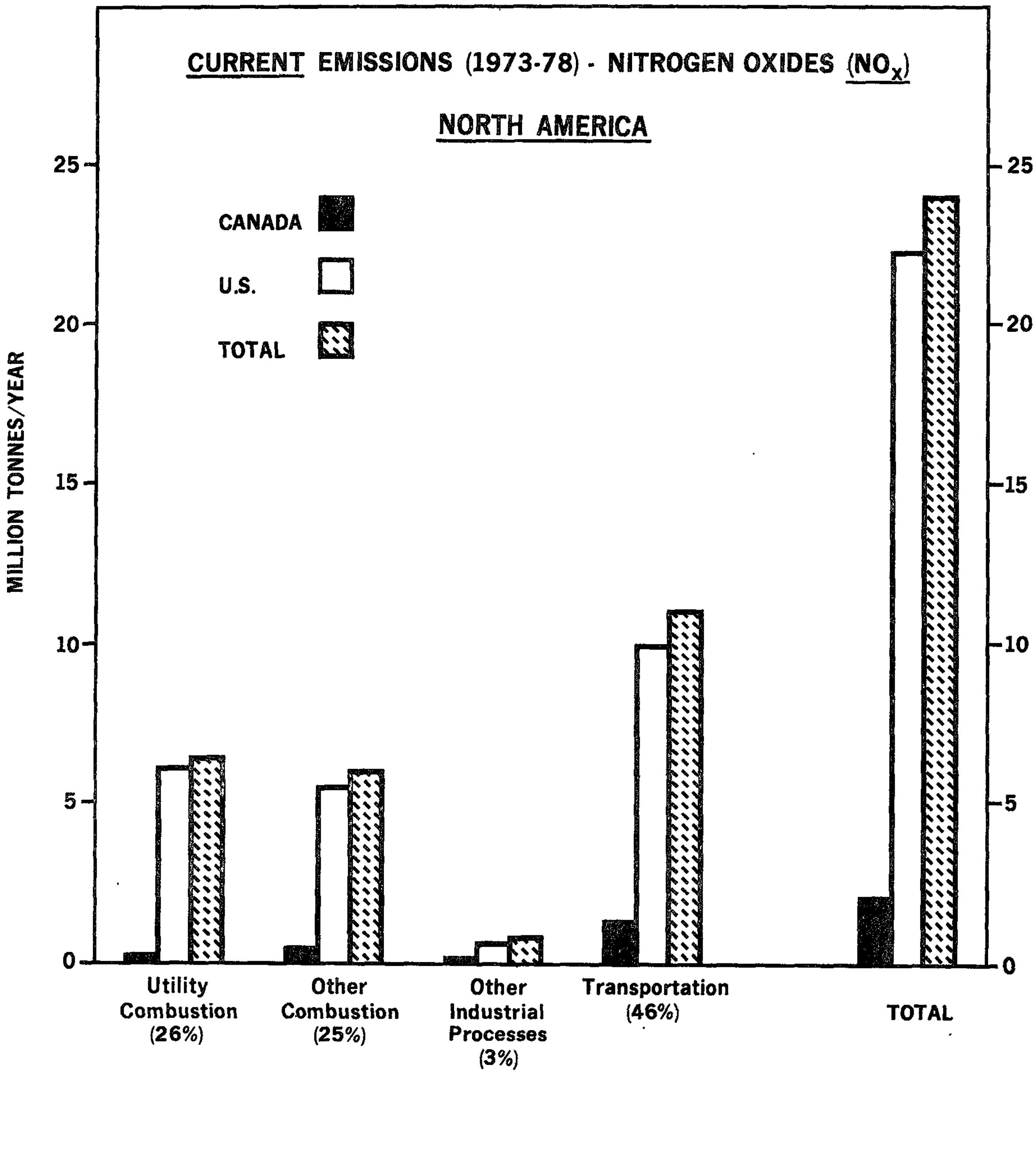
References: 1,2

Current emissions - NO_x - North America (graph 4)

In eastern North America nitrogen oxides contribute on average about 1/3 of the acidity of rain, whereas sulphur oxides contribute about 2/3.

Total NO_x emissions amount yearly to 24.1 million tonnes. The ratio of U.S. to Canadian emissions is approximately 10 to 1 (22.2 vs 1.9 million tonnes) and close to half of the combined emissions come from the transportation sector, mainly the gas-powered motor vehicle. This is an important source of emissions, but it is also widely dispersed geographically. It's contribution to the acid rain problem is still not well determined.

One quarter of total U.S.-Canada combined NO_x emissions are contributed each by power plants and by other combustion processes (residential, commercial, industrial fuel combustion). Power plants, as significant (in most cases)



CURRENT EMISSIONS (1973-78) - NITROGEN OXIDES (NO_x)
NORTH AMERICA
CANADA
U.S.
TOTAL
MILLION TONNES/YEAR
0
5
10
15
20
25
Utility Combustion (26%)
Other Combustion (25%)
Other Industrial Processes (3%)
Transportation (46%)
TOTAL

individual point sources of NO_x (and also of SO_2), therefore play a determined role in the acid rain issue.

It is of note that in addition to being one of the important precursor pollutants to acid rain, nitrogen oxides are also precursors to the formation of ozone and to the photochemical oxidants or smog problems experienced by some North American major urban areas in the last decade or so.

Reference: 1

Magnitude and distribution of SO_2 emissions - Eastern North America (figure 1)

In the United States, the large majority of SO_2 emission sources are located in the mid-west and northeastern states where they can affect, through atmospheric transport, and transformation to acidic compounds, sensitive environmental (aquatic, terrestrial, and others) receptors in the northeastern United States and eastern Canada. This situation is largely due to the prevailing wind regime which, over much of this area, is one of westerly winds. The highest density of sulphur dioxide emissions is in the upper Ohio River Valley region (eastern Ohio, northern West Virginia, western Pennsylvania) where are located a number of large high sulphur coal burning power plants with little or no control of their emissions.

In Canada the two highest density areas of SO_2 emissions are the Sudbury, Ontario region and the Noranda, Quebec region where the two most significant (from an emissions perspective) Canadian non-ferrous smelters are located.

The SO_2 emission density of the 80 km x 80 km grid square where Sudbury,Ontario is located is one and one half times greater than the density of the most significant grid square located in the U.S. (the West Pittsburg, PA and upper Ohio River Valley area). Then come a number of high density grid

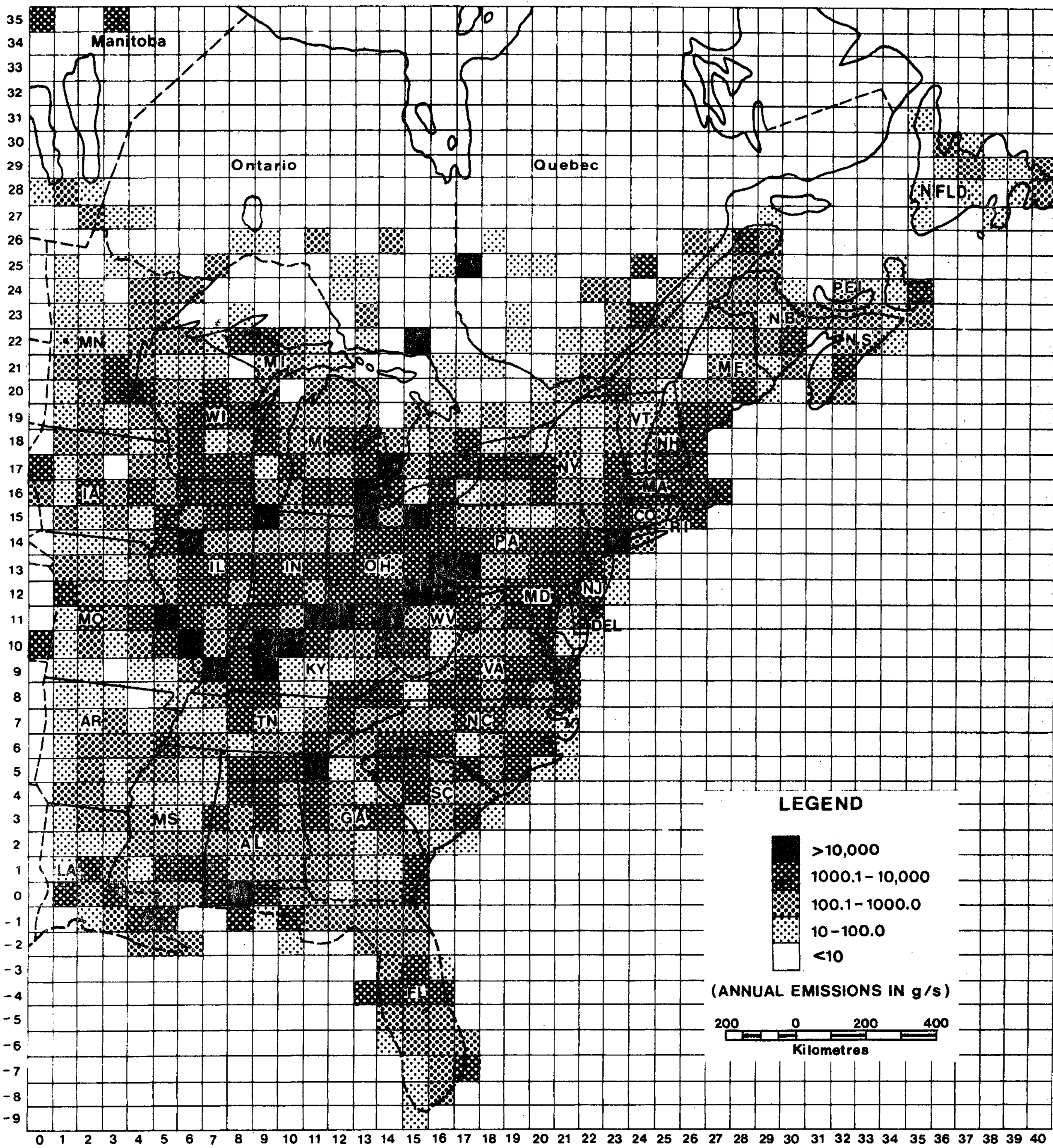


FIGURE 1. MAGNITUDE AND DISTRIBUTION OF SULPHUR DIOXIDE (SO_2) EMISSIONS IN EASTERN NORTH AMERICA

Source: U.S.A. emissions from SURE II data base.
Canadian emissions from Environment Canada.

squares in Ohio, West Virginia and Michigan before the Noranda, Quebec grid is reached (in 8th position). This is followed by sixteen other highest density grids (darker squares) all located in the U.S. Each of these darker grid squares represents SO_2 emissions, on an annual basis, exceeding about 300,000 tonnes.
References: 1,3

Magnitude and distribution of NO_x emissions - Eastern North America (figure 2)

The geographic distribution of emissions of nitrogen oxides is more uniform than that for sulphur dioxide because the former are intimately related to population density and to transportation activity. There are nevertheless a few isolated areas of highest emission densities, namely the New York-New Jersey areas and around Detroit, Michigan and Gary, Indiana, the last two being related largely to fuel combustion for heavy industrial activity.

The upper Ohio River Valley is also a synonym of significant NO_x emission densities, a situation which is again caused by the cluster of uncontrolled coal-fired power plants located in that source region. Except for a few areas (e.g. south-central Ontario, southern Quebec), the Canadian picture is one of low NO_x emission densities almost throughout, and is a reflexion of the relatively low magnitude of NO_x emissions in eastern Canada.

Reference: 1

Simplified transboundary flux estimate for sulphur (graph 5)

The simplified sulphur budget for eastern North America pictorially indicates the quantities of sulphur emitted by each region, the quantities that, on a yearly average, are exported to the other country, how much is deposited and how much is leaving the regions to the east, i.e. over the Atlantic Ocean (the values indicated must be multiplied by two to convert the sulphur to the equivalent sulphur dioxide).

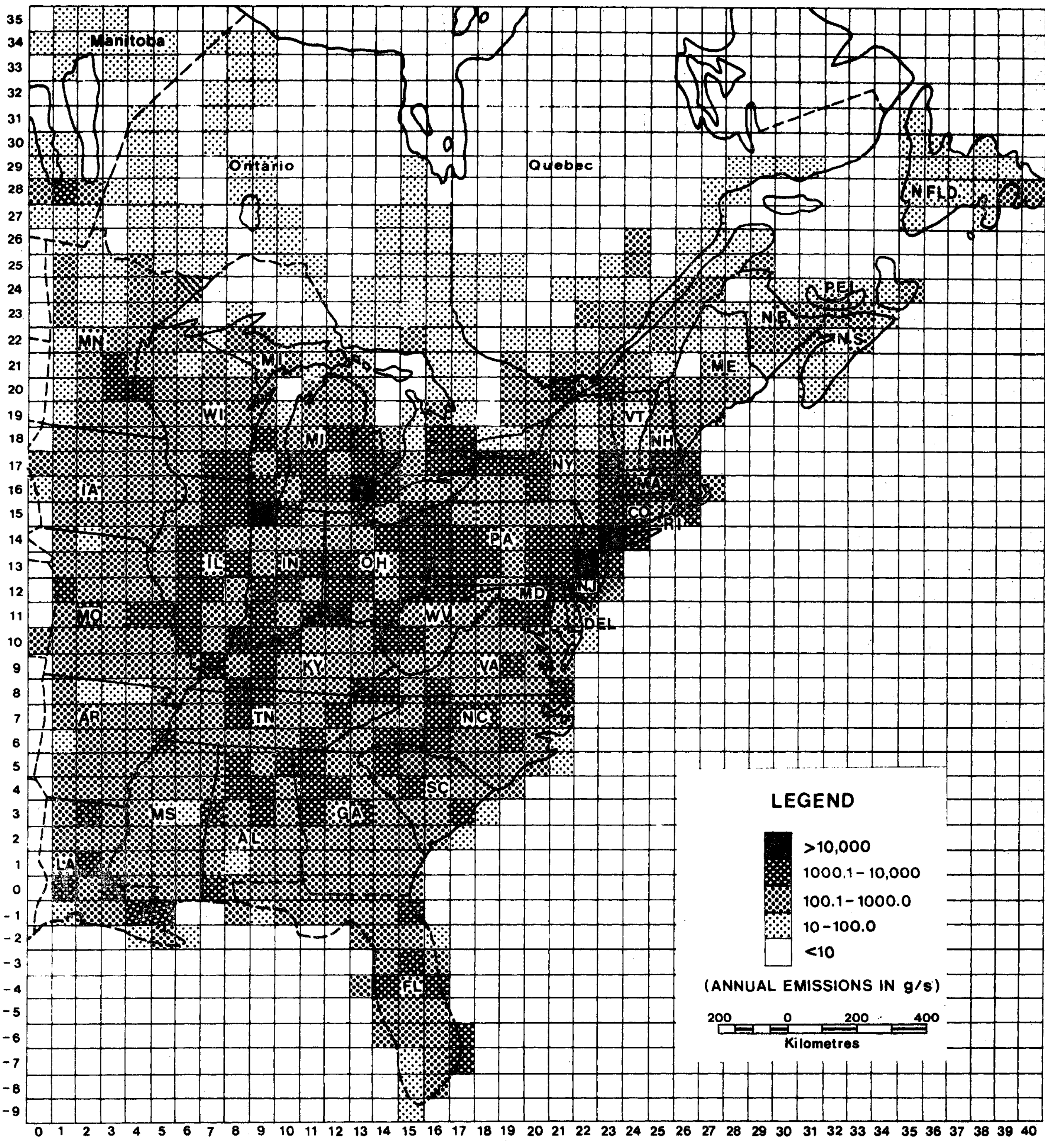


FIGURE 2. MAGNITUDE AND DISTRIBUTION OF EMISSIONS OF NITROGEN OXIDES (NO_x) IN EASTERN NORTH AMERICA

Source: U.S.A. emissions from SURE II data base.
Canadian emissions from Environment Canada.

For example, it is estimated that of the total eastern United States output of 10.5 million tonnes of sulphur, about 2 million tonnes are exported north to eastern Canada. This quantity equals approximately what is emitted yearly in eastern Canada. Canada is also an exporter of some of its emissions and it sends to the south about 0.6 million tonnes of sulphur per year. The net result is that the United States contribute more than half of the man-made sulphur which eventually falls in acid form in eastern Canada. This obviously varies according to how close to the border the receptor region is, and according to the predominant winds which vary from season to season. As an added example, the U.S. contribution to acid fallout in the southern parts of Ontario may reach 80 percent.

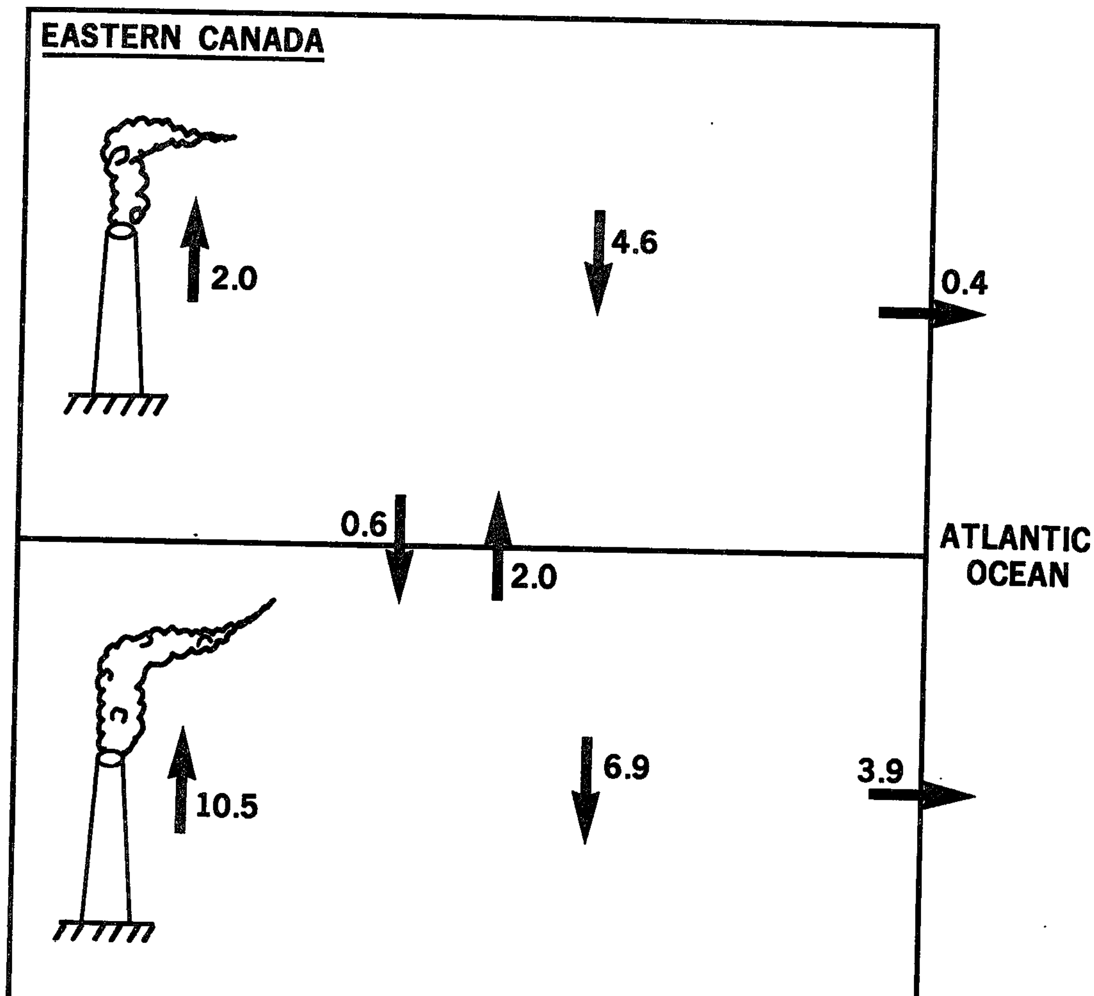
As in most budgets there are uncertainties in this sulphur budget for eastern North America. One of these uncertainties is the actual amount of sulphur emissions contributed yearly by eastern U.S. sources. It appears indeed possible that the value used for this budget (10.5 million tonnes of sulphur) may significantly underestimate the actual amounts being emitted. This is being investigated further.

References: 1,3,4

Historical and projected SO_2 emissions - Canada (graph 6)

Historical aspects

Total sulphur dioxide emissions in Canada in 1978 ran at about 4.5 million tonnes, i.e. at approximately the same level as in the mid-50's, after having peaked to a maximum of 6.0 million tonnes in the early seventies. This significant (by Canadian standards) fluctuation was largely due to the situation in the non-ferrous smelting industry over the same time frame and, to a lesser extent, by increased emissions from power plants and from other industrial sources.



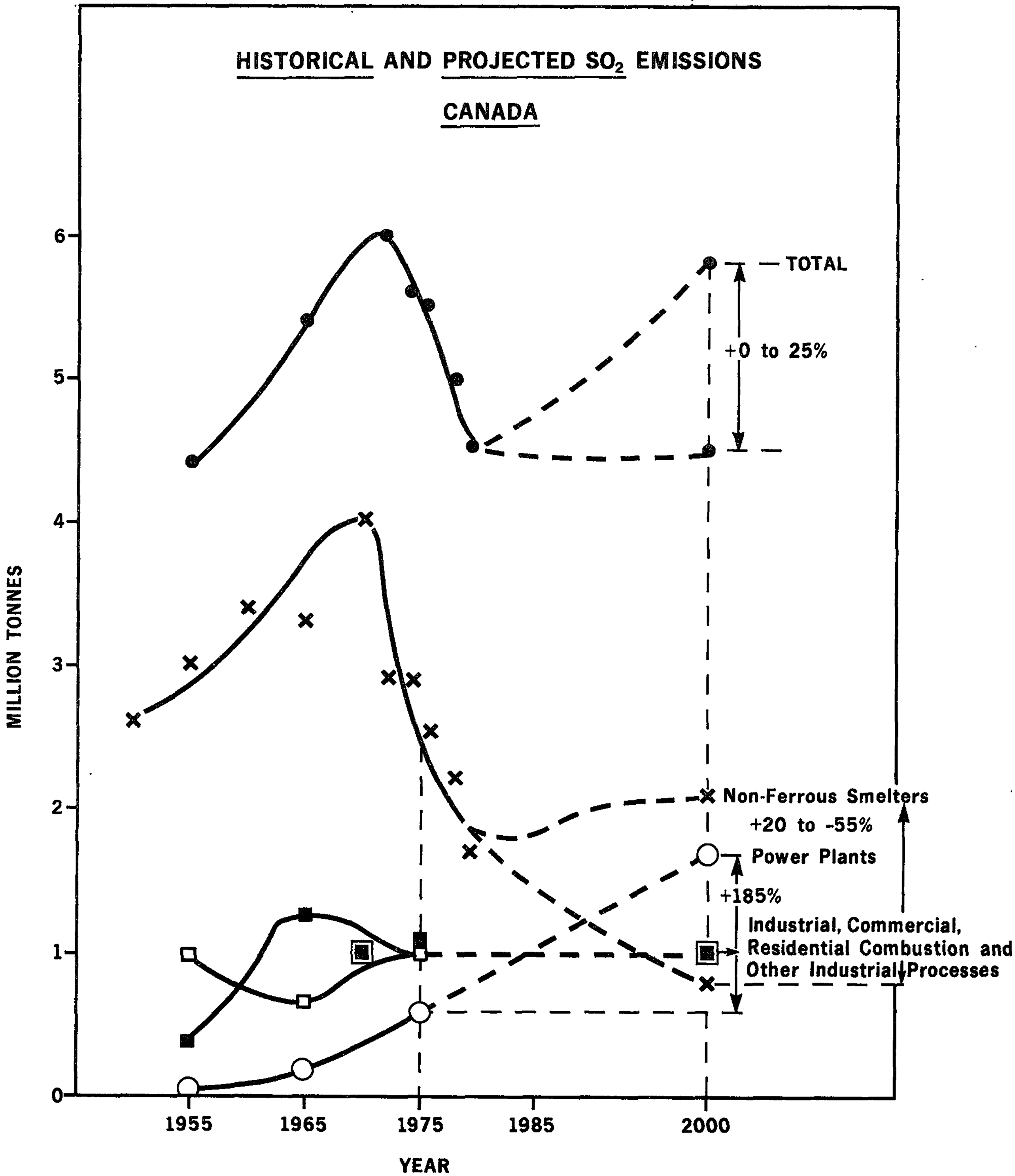
SIMPLIFIED TRANSBOUNDARY FLUX ESTIMATES
(MILLION TONNES OF SULPHUR/YEAR)

In the Canadian copper-nickel non-ferrous smelting industry the emission level increased approximately 55% from 2.6 million tonnes in 1950 to 4.0 million tonnes in 1970. The increase in emissions was largely the result of increased capacity and production by the addition of new smelters in Murdochville, Quebec in 1955 and in Thompson, Manitoba in 1960. Proportionally however, due to some process improvements (increased pyrrhotite rejection) and the shifting of production to the new facilities, the increase in emissions was not as substantial as the production increases.

During the period from 1970 to 1979, the effects of environmental pressures being brought to bear on the non-ferrous smelting industry were felt. Emissions continuously decreased from their peak of about 4.0 million tonnes in 1970 to a level of about 1.8 million tonnes in 1979. The decrease in emissions can be attributed to process improvements, production cutbacks, the closure of the Coniston smelter in 1972, and the addition of acid plants at the Murdochville smelter in 1975 and at the Falconbridge smelter in 1978.

The total emission levels in the non-ferrous smelting industry for the period 1978-79 are however not indicative of what might have been expected on an annual basis because a six month strike which spanned both years at the largest Canadian smelter served to artificially reduce emissions. Nevertheless, under a recently proposed government control order SO_2 emissions at that smelter would be restricted starting in 1980 such that overall emissions from the industry would be, in 1980, only slightly higher than the levels of 1978-79.

Emissions from Canadian power plants were at a negligible level of 0.04 million tonnes in the mid-50's. These emissions however have not ceased to increase since and in the mid-70's totalled 0.6 million tonnes. Sulphur dioxide from other industrial processes increased from 0.4 million tonnes in 1955 to about 1.1 million tonnes in the mid-70's due largely to increased productivity because of favourable economic conditions. The emissions due to the combustion of fuels for industrial, commercial, and residential purposes



HISTORICAL AND PROJECTED SO_2 EMISSIONS
CANADA
MILLION TONNES
0
1
2
3
4
5
6
YEAR
1955
1965
1975
1985
2000
TOTAL
+0 to 25%
Non-Ferrous Smelters
+20 to -55%
Power Plants
+185%
Industrial, Commercial, Residential Combustion and Other Industrial Processes

decreased first from 1955 to 1965, mostly because of a switch from coal to other cleaner burning fuels, before increasing from 1965 to a level in the mid-70's identical to that of the mid-50's. The increase can again be largely attributed to greater industrial activity.

Projections

For the remainder of the century, total Canadian emissions are expected to remain at current levels of about 4.5 million tonnes, or to increase by a maximum of 25%. This will depend largely on the amount of emission control that will be implimented in the non-ferrous smelters. The range of projected values from this sector alone vary from + 20 percent over the 1978-79 levels of 1.8 million tonnes to -55 percent of the same levels. The validity of the first scenario would be dependent on the existence of a status quo with respect to production capacity, pollution control and technological innovation and implementation. It is an unlikely situation because it disregards the future short term effects of recessions, booms, or labour problems, and the long term effects of pressures from environmental quarters to improve the existing situation.

The second scenario for the non-ferrous smelters (decrease of 55 percent from the 1978-79 levels) denotes the 'best case' effect. It incorporates changes attributable to both technological improvements and environmental pressures, and assumes that short term fluctuations due to recessions, booms, or labour problems will be averaged out on the long term basis. Probably the most likely situation is one that lies somewhere within the range established by the first and second scenario, because it accounts for the large amount of uncertainty associated with the other projections. It is noted that under present conditions the environmental conscience of Canadian society has been aroused by an awarness of the real dangers posed by acid precipitation. This arousal should in all probability ensure that some action will be taken to reduce emissions.

The projections for the non-ferrous smelting sector are expected to be combined with a three-fold increase in SO_2 emissions from the utility sector in Canada. This projection is based on the amount and type of coal which is likely to be used to generate electricity in each of the provinces by the year 2000, on the assumption that the current control situation for coal-fired power plants will remain unchanged, and on a status quo regarding the use of nuclear power stations to replace some of the energy requirements. It is likely a worst case projection but also a real possibility.

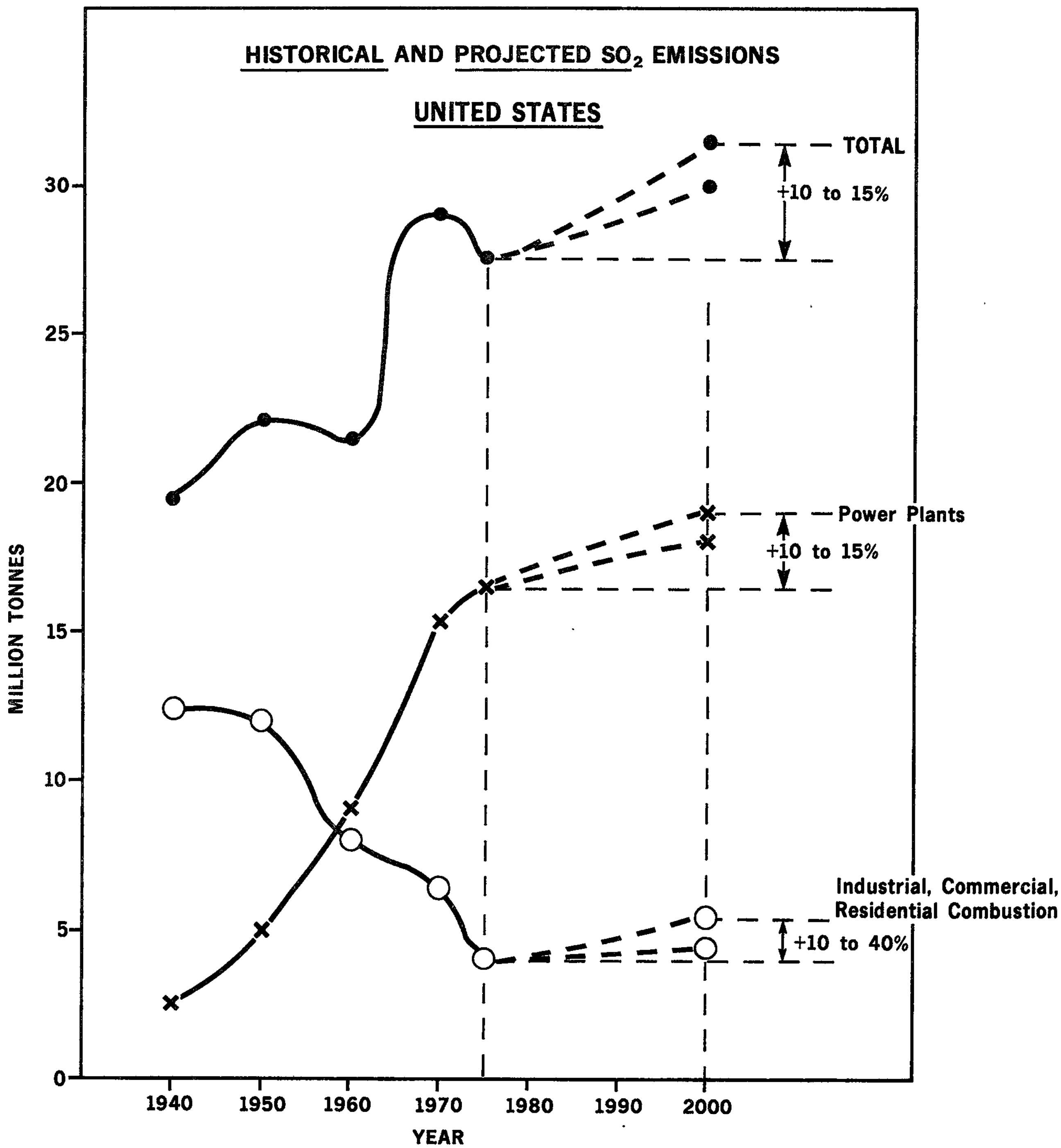
Sulphur dioxide emissions from other industrial processes and from the combustion of fuels for industrial, commercial, and residential purposes are not expected by the year 2000 to be significantly different from their current levels although there may be a switch in terms of the major contributing industrial sector (e.g. natural gas processing, tar sands).

References: 1,2,3,6

Historical and projected SO_2 emissions - United States (graph 7)

Historical aspects

Over the last 25 years total United States emissions of sulphur dioxide have increased from a level of about 22 million tonnes to about 28 million tonnes, an increase of about 30 percent. This overall increase can be attributable to a more than trebling of emissions from the utility sector, from 5.0×10^6 tonnes in 1950 to 16.5×10^6 tonnes in 1975. During the same period there was a significant decrease in emissions from residential, commercial, and industrial fuel combustion sources as they switched from coal to other cleaner-burning fuels. This significant decrease from a level of about 12.0×10^6 tonnes in 1950 to 4.0×10^6 tonnes in 1975 helped to partially offset the impact of the large increase in power plant emissions. Sulphur dioxide emissions from other industrial processes remained virtually unchanged over the 1950-75 period.


HISTORICAL AND PROJECTED SO_2 EMISSIONS
UNITED STATES
TOTAL
+10 to 15%
Power Plants
+10 to 15%
Industrial, Commercial, Residential Combustion
+10 to 40%
MILLION TONNES
0
5
10
15
20
25
30
1940
1950
1960
1970
1980
1990
2000
YEAR

Projections

Emission trends to the end of the century are expected to be modestly upward (+ 10 to 15 percent) for the electric utility sector as new American power plants are required to install sulphur-removing scrubbers and if older uncontrolled plants are phased out of service. This is likely an optimistic scenario in light of the recently proposed oil back-out policy and its lack of strict pollution control requirements which was approved by the House of Representatives in July 1980.

The projected increase in emissions from power plants will be coupled with a significant (up to 40 percent) increase in emissions from the combustion of fuels for industrial, commercial, and residential purposes as these sources are required to once more depend on coal as their primary fuel source. The net result for the total emissions of sulphur dioxide in the United States by the turn of the century will be an increase of 10 to 15 percent above current levels, i.e. total emissions should reach 30 to 31.5 million tonnes.

It should be noted that the terminology used to describe the various increases or decreases in emissions (e.g. modest, significant) is identical for both Canada and the U.S. However, it must be fully recognized that the absolute magnitude of these variations is different in both countries. For example, a modest increase of 15% in total Canadian emissions is equivalent to an increase of about 0.7 million tonnes. The same modest increase in the U.S. translates into an increase of 4.1 million tonnes, or six times the Canadian increase.

References: 1,3,5

Historical and projected NO_x emissions - Canada (graph 8)

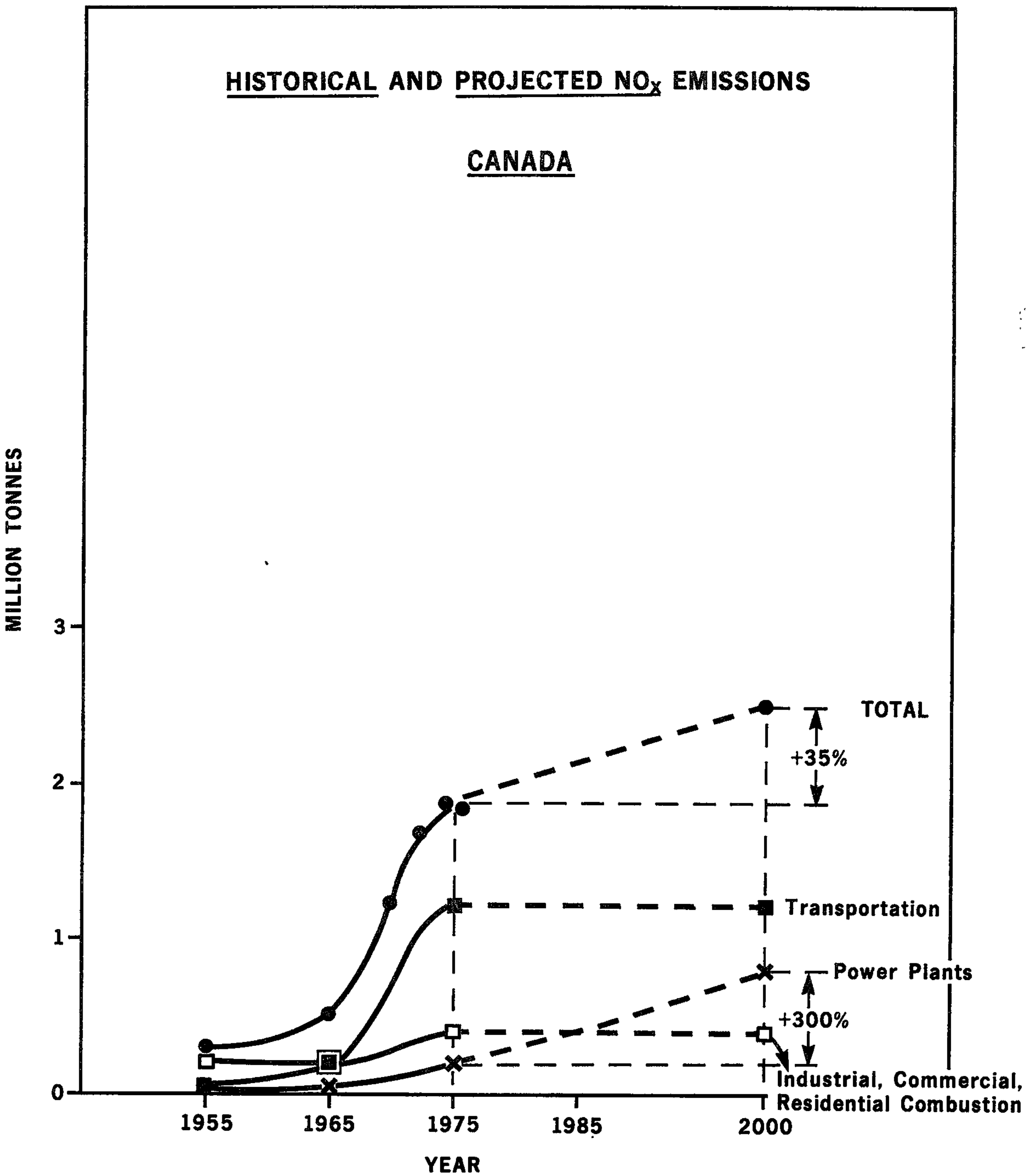
There has been a significant rise in emissions of nitrogen oxides over the period from 1955 to 1975 which has been caused largely by increases in the transportation sector, mainly the gas-powered motor vehicle. Emissions from this sector ran at 0.06 million tonnes in the mid-50's and have since increased to more than 1.0 million tonnes. To a lesser extent the generation of electricity by thermal power plants also has gradually added to the total NO_x emissions in Canada. Emissions from power plants, which were at 0.01 million tonnes in 1955, totalled 0.25 million tonnes in 1975.

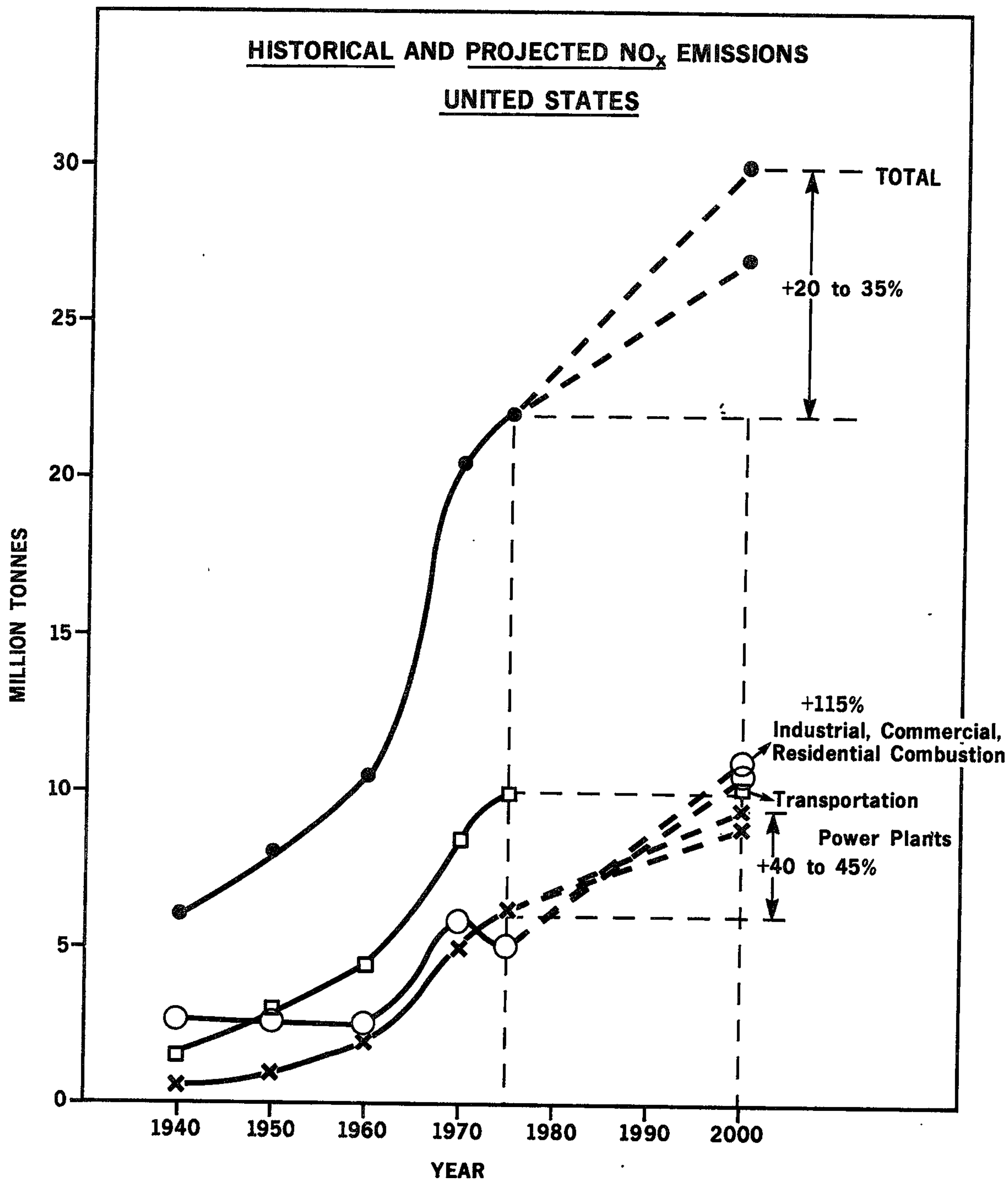
Future Canadian emissions of nitrogen oxides are expected to rise significantly over the mid-70's level of 1.9 million tonnes to approximately 2.5 million tonnes by the year 2000. The increase is expected to be almost entirely attributable to a continuing increase in power plant emissions. As was the case for SO_2 emissions, this projection is based on the amount and type of coal likely to be burned then, and on the assumption of a status quo vis-à-vis pollution controls and the use of nuclear power stations to replace some of the energy requirements. Nitrogen oxide emissions from all other sources are not expected to vary significantly from their current (mid-70) levels.

References: 1,3

Historical and projected NO_x emissions - United States (graph 9)

Trends in United States nitrogen oxide emissions have been strongly upward with almost a trebling of emissions over the past twenty-five years, from a level of 8.0 million tonnes in 1950 to about 22.0 million tonnes in 1975. This substantial increase has been caused largely by two major factors: a six-fold increase in utility sector emissions (from 1.0 to 6.0 million tonnes) and a three-fold increase in emissions from transportation activity, mainly the gas-powered motor vehicle (from 3.0 to 10.0 million tonnes).


HISTORICAL AND PROJECTED NOx EMISSIONS
CANADA
MILLION TONNES
3
2
1
0
1955
1965
1975
1985
2000
YEAR
TOTAL
+35%
Transportation
Power Plants
+300%
Industrial, Commercial,
Residential Combustion



HISTORICAL AND PROJECTED NO_x EMISSIONS
UNITED STATES
MILLION TONNES
30
25
20
15
10
5
0
1940
1950
1960
1970
1980
1990
2000
YEAR
TOTAL
+20 to 35%
+115%
Industrial, Commercial, Residential Combustion
Transportation
Power Plants
+40 to 45%

Significant increases ranging from 20 to 35 percent are predicted for the remainder of the century, which implies that total U.S. emissions of NO_x may reach 30 million tonnes yearly by then. This will be due in part to power plant emissions which will increase by 40 to 45 percent even though new utility plants will have to meet strict emission controls for nitrogen oxides. This projection does not take into account the proposed oil backout policy mentioned earlier which was just recently processed through the U.S. House of Representatives and which does not contain any firm commitment towards reducing substantially the emissions from those plants which will fall under the conversion program. The emissions from the combustion of fuels for industrial, commercial, and residential purposes are also expected to contribute substantially to the overall increase in U.S. NO_x emissions as they will move from a level of about 5.0 million tonnes in 1975 to close to 11.0 million tonnes by the year 2000 when coal is once again used as a primary fuel source in industrial sources. Transportation sector emissions, on the other hand, are not expected to vary significantly from their current levels because of larger numbers of lower emitting vehicles (if projected automobile regulations are not relaxed).

References: 1,3,5

References

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