NATIONAL INVENTORY OF SOURCES AND EMISSIONS OF CADMIUM (1972)*

Pollution Data Analysis Division
Air Pollution Programs Branch
Air Pollution Control Directorate

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ABSTRACT

Atmospheric emissions of cadmium from various Canadian sources have been estimated for the year 1972. The data presented in this report are summarized in Table 1 and Figures 1 and 2. Total cadmium emissions to the atmosphere in 1972 are estimated at 560 tons. The largest contributor is the primary copper and nickel industry which accounts for 78.1% of the total. The combustion of fuel in stationary sources accounts for a further 16.9%. On a geographic basis the Province of Quebec, centre of the Canadian primary copper industry, accounts for 75.1% of total cadmium emissions.

Results are first approximations of the actual quantities emitted due to paucity of data. The inventory serves to place the various emission sources in perspective and the reader is cautioned not to use emission estimates out of context of this inventory.

RÉSUMÉ

On a fait l'estimation des émissions de cadmium dans l'atmosphère en 1972 par les différentes sources canadiennes. Le tableau 1 et les figures 1 et 2 résument les données contenues dans le présent rapport. Les émissions ont été estimées à 560 tonnes, dont 78.1% sont attribuables à l'industrie du cuivre et du nickel de première fusion tandis que 16.9% proviennent de la combustion dans les sources fixes. Géographiquement c'est la province de Québec, capitale canadienne de l'industrie du cuivre de première fusion, qui contribue à 75.1% des émissions.

Étant donné le peu de données disponibles ces chiffres constituent une première approximation. L'inventaire de ces emissions a pour but de déterminer l'importance relative des diverses sources d'émissions; on invite donc le lecteur à ne pas utiliser ces valeurs estimatives hors contexte.

TABLE 1 CADMIUM EMISSIONS BY PROVINCE AND SECTOR, 1972 (lb)

Sector	Province B.C.	Alta.	Sask.	Man.	Ont.	Que.	Nfld.	Maritimes	N.W.T. Yukon	**Total Canada**	% Total
INDUSTRY											
Primary copper and nickel production	–	N*	–	32 000	74 000	770 000	–	–	–	**876 000**	78.1
Primary lead production	8 401	–	–	–	–	–	–	6 079	–	**14 480**	1.3
Primary zinc production	572	–	–	1 649	306	33	–	–	–	**2 560**	0.2
Primary iron and steel production	35	165	900	230	757	707	–	1 359	–	**4 153**	0.4
Specialty copper products	–	–	–	–	8 900	–	–	–	–	**8 900**	0.8
Iron and steel foundries	336	26	11	137	4 786	1 728	22	249	–	**7 295**	0.7
Nonferrous alloys	17	–	–	–	1 666	17	–	–	–	**1 700**	0.2
Miscellaneous sources	←				1 343				→	**1 343**	0.1
FUEL COMBUSTION/ STATIONARY SOURCES											
Power generation	95	3 245	3 674	613	424	590	840	16 210	132	**25 823**	2.3
Industrial and commercial	9 735	1 332	1 370	1 772	40 324	58 821	597	32 543	3 241	**149 735**	13.3
Domestic	1 112	83	166	188	4 980	6 410	314	1 588	152	**14 993**	1.3
TRANSPORTATION											
Motor vehicles	70	68	38	33	169	97	6	22	9	**512**	0.1
Rail transport	203	296	92	183	424	306	42	108	3	**1 657**	0.2
Shipping	–	16	70	28	1 839	1 859	–	–	N	**3 812**	0.3
Aviation	←				N				→		
Tire wear	17	13	7	6	50	38	2	9	N	**142**	**<0.1**
SOLID WASTE INCINERATION	–	–	110	2 113	4 445	612	–	393	–	**7 673**	0.7
PESTICIDE APPLICATION	5	10	10	10	15	10	5	5	N	**70**	**<0.1**
TOTAL	**20 598**	**5 254**	**6 448**	**38 962**	**143 085**	**841 228**	**1 828**	**58 565**	**3 537**	**1 120 848 (560 tons)**	
% TOTAL	1.8	0.5	0.6	3.5	12.8	75.1	0.2	5.2	0.3		100

*N–negligible

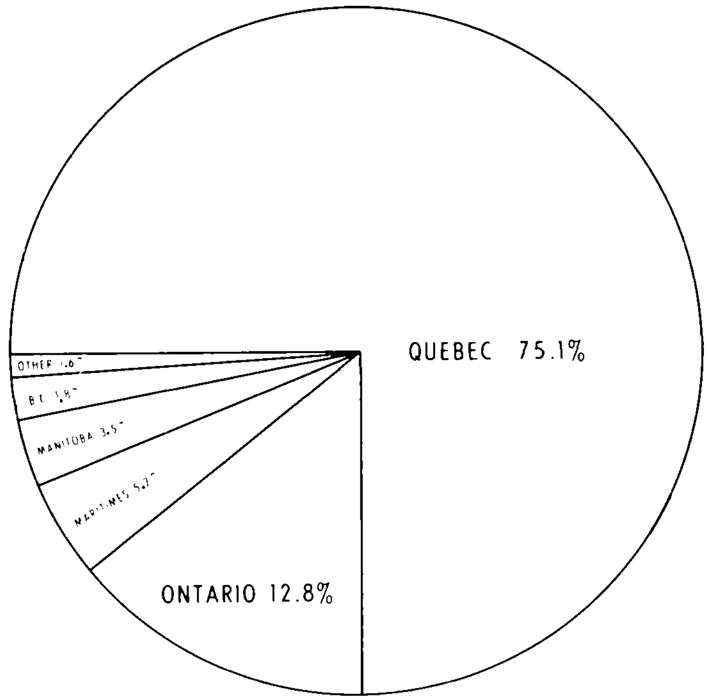

FIGURE 1 PERCENT CADMIUM EMITTED BY PROVINCE, 1972

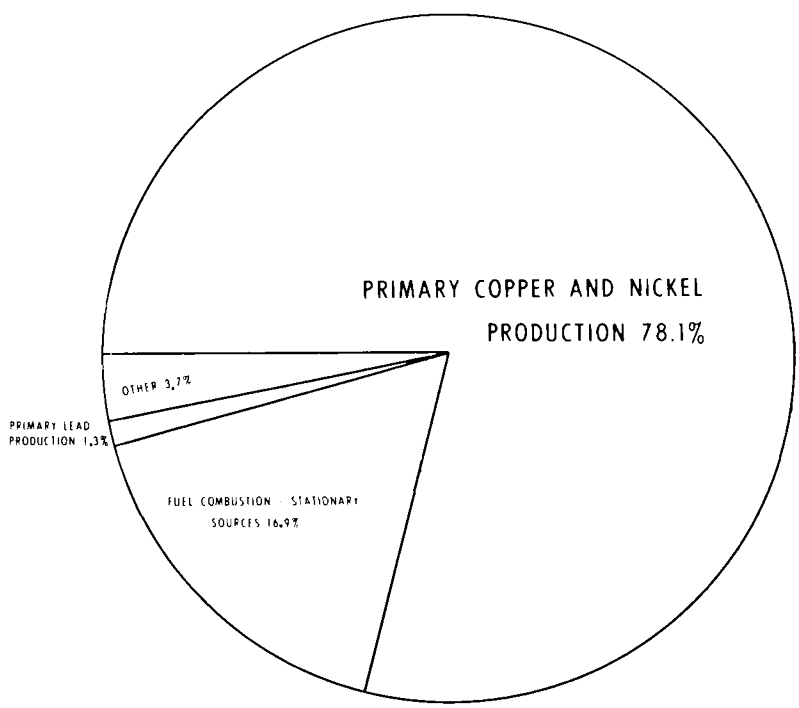

FIGURE 2 PERCENT CADMIUM EMITTED BY SOURCE, 1972

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1 INTRODUCTION

1.1 Scope

The purpose of this report is to identify and quantify sources of atmospheric emissions of cadmium in Canada for the year 1972. The information contained in this report was obtained from a literature survey, a computer search conducted at the National Science Library and from previous inventory studies. Information was also gathered from a specifically designed questionnaire which was sent to approximately 1050 plants and received a response of 51%. Details on response rate and quality of returns are given in the Appendix. As far as possible emission estimates were based on source testing data applicable to Canadian conditions.

1.2 Sources and Uses of Cadmium

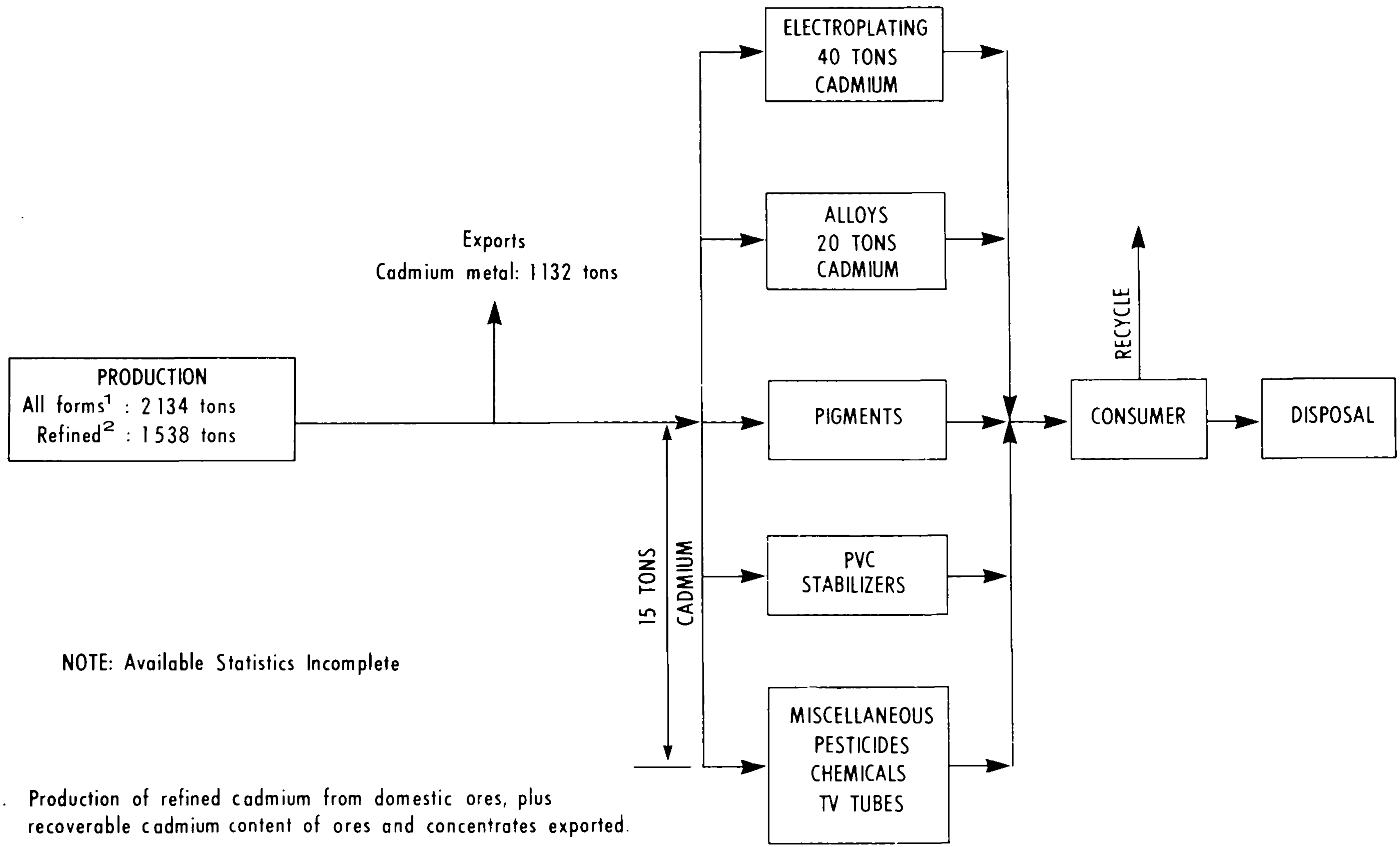
In nature, cadmium occurs predominantly as a sulphide greenockite, associated with zinc sulphide ores, especially the common zinc ore mineral sphalerite. This association with zinc minerals continues during the milling process and cadmium is recovered as a by-product of zinc refining from zinc concentrates which normally contain 0.1%-0.3% cadmium (1). Canadian zinc ores contain up to 0.07% cadmium.

Cadmium is recovered at electrolytic zinc plants as a precipitate or metal sponge produced during the purification of zinc electrolyte. In Canadian plants, the metal is then refined either by the electrolytic process, where cadmium is redissolved in sulphuric acid and plated out in electrolytic cells, or by a purification process in which the sponge is briquetted, melted in an electric furnace, dezinced and cast (1). Sources and uses of cadmium are identified in Figure 3.

Cadmium is a soft, silver-white metal used mainly for electroplating other metals or alloys, principally iron and, to a lesser extent, copper, to protect them against oxidation. The cadmium coating protects the metal by physical enclosure and by sacrifical corrosion if the coating is broken. Cadmium-plated articles are used in the manufacture of automobiles, household appliances, aircraft, radios, television sets and electrical equipment. Plating accounts for about half the total consumption of cadmium (Figure 3).

Another major use is in the manufacture of pigments. Yellow and orange colors are obtained from cadmium sulphides, while pink, red and maroon colours are obtained from cadmium sulphoselenides (1).

Cadmium is a valuable alloying metal and has applications in cadmium-silver solders and in cadmium-tin-lead-bismuth fusible or low-melting-point alloys for automatic sprinkler systems, fire detection equipment, and valve seats for high-pressure gas containers. Low-cadmium copper (about 1% cadmium) is used in the manufacture of trolley and telephone wires to improve tensile strength. Low-cadmium copper is also employed in automobile radiator finstock, replacing the low-silver copper formerly used (1).



1. Production of refined cadmium from domestic ores, plus recoverable cadmium content of ores and concentrates exported.

2. Refined cadmium as a by-product of the primary zinc industry, as reported in questionnaire returns.

FIGURE 3 SOURCES AND USES OF CADMIUM, 1972

Cadmium stearates act as stabilizers in the production of polyvinyl chloride plastics, and cadmium phosphors are used in both black and white, and colour television tubes (1).

Another growing application is in the production of nickel-cadmium storage batteries. These batteries are considerably more expensive than the standard lead acid battery, but have a longer life and a higher peak power output. They are also smaller, and are superior in low-temperature operation (1).

2 INDUSTRIAL EMISSIONS

2.1 Primary Copper and Nickel Production

There were six primary copper smelters in Canada in 1972, three of which also produced primary nickel. One other company produced the remainder of the primary nickel and also a small amount of copper sulphide as a by-product. A small amount of copper matte was also produced as a by-product of primary lead production. A total of 801 690 tons of recoverable copper and 258 087 tons of nickel were produced in Canada in 1972 (2,3).

2.1.1 Process Description. The type of process and the process stages required depend primarily on the characteristics and chemical composition of the ores. The most common method of producing primary copper and nickel is the pyrometallurgical process and consists of the following basic process steps:

Concentration. Low-grade sulphide ores are concentrated by gravity or flotation.

Roasting. Concentrates are roasted to drive off most of the sulphur in preparation for subsequent smelting and converting reactions.

Smelting. In this stage the charge is melted, usually in a reverberatory furnace, where it separates into a matte and a slag. Matte is a mixture of the recoverable metal sulphides, while slag is a mixture of discardable oxides.

Converting. The mattes are converted, through a series of chemical reactions to the crude metals.

Anode Furnace and Electrolytic Refining. The crude copper or nickel is then cast into anodes to be refined by electrolysis.

Cathode Melting. Electrolytic copper is melted under reducing atmosphere in a shaft-type furnace to be cast into billets, slabs, etc. for marketing.

Figure 4 is a typical flow diagram for the pyrometallurgical process. Nickel is also produced by the hydrometallurgical process which is practised at one plant in Canada.

2.1.2 Emissions. The main atmospheric emission sources in primary copper and nickel production are the roasters, furnaces, and converters. Emissions from operations such as ore handling and anode furnace are negligible in comparison. Cadmium is emitted primarily in the form of cadmium oxide.

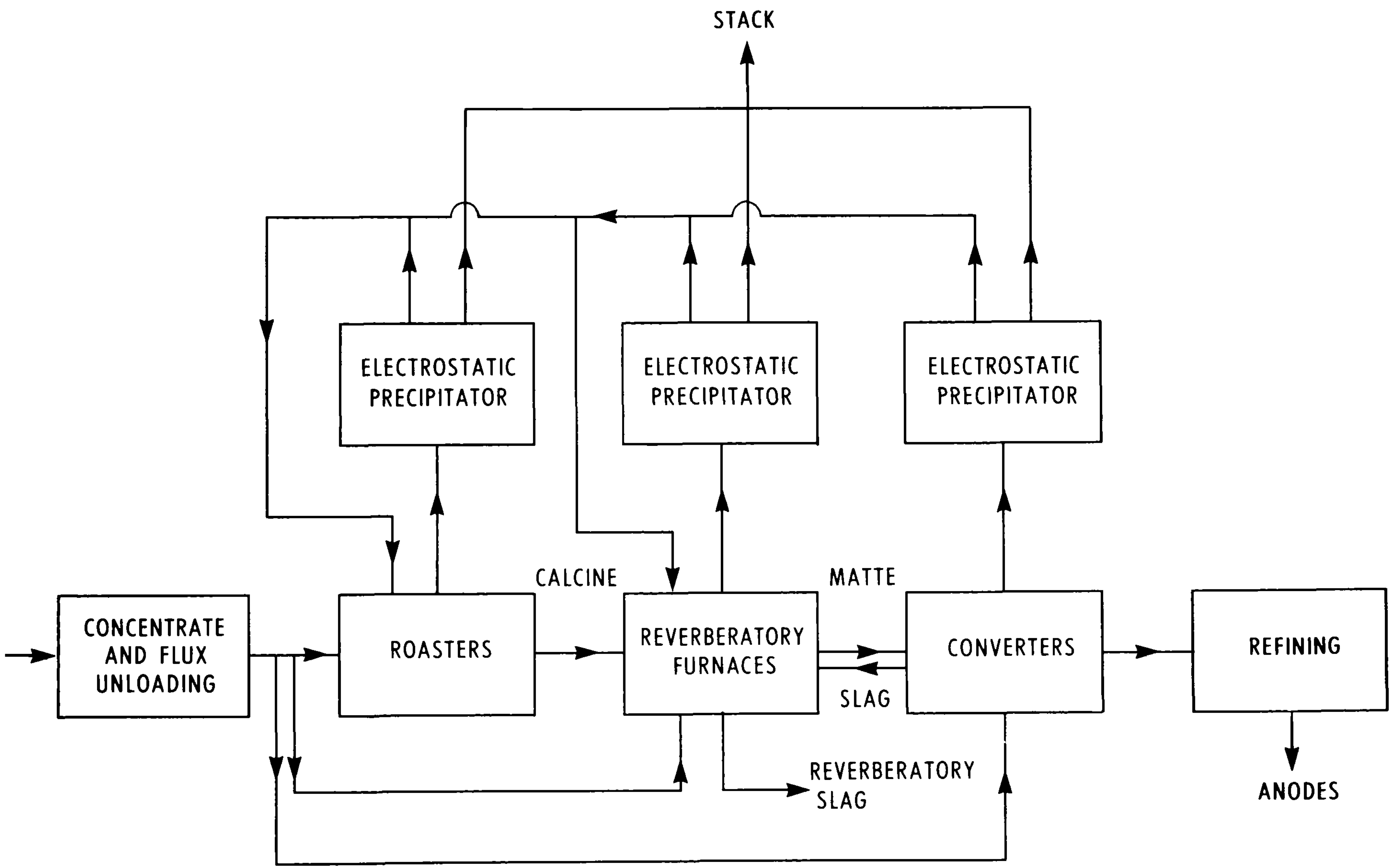


FIGURE 4 PRIMARY COPPER AND NICKEL PLANT FLOW DIAGRAM

Because of process variations from one company to the other, emission factors for various process stages could not be compared.

Most of the companies surveyed reported source test data as a basis for calculating cadmium emissions. For the remainder cadmium emissions were estimated as an assumed fraction of reported zinc emissions.

A similar emissions inventory in the United States (4) does not consider emissions of cadmium from primary copper and nickel production.

Total emissions of cadmium to the atmosphere from primary copper and nickel production for 1972 are estimated at 876 000 lb (438 tons).

2.1.3 Particle Size Distribution. Information received on particle size distribution for particulate emissions from primary copper and nickel smelters is summarized in Table 2.

2.2 Primary Lead Production

There were two primary lead producers in Canada in 1972, producing a total of 204 452 tons of lead. Small amounts of copper matte, totalling 3677 tons, were a by-product of lead refining operations.

2.2.1 Process Description. The ore is concentrated and then lead is extracted by first partially oxidizing the concentrate in a sintering plant. The concentrate may also be process-dried prior to sintering. The partially roasted concentrate is then smelted in a blast furnace where the lead sulphide is oxidized by air to lead oxide, lead sulphate and sulphur dioxide. The lead oxide and lead sulphate then react with carbon and carbon monoxide producing lead metal, carbon dioxide, sulphur dioxide, and a slag. The lead is further refined by either electrolysis or chemical precipitation from the molten metal.

2.2.2 Emissions. The main cadmium emission sources from primary lead production are:

Sinter Plant. One plant has an acid plant which results in low cadmium emissions in the form of cadmium oxide. The other plant has scrubbers. Total emissions of cadmium to the atmosphere from this source in 1972 are 880 lb or 0.44 ton.

Blast Furnace. During the blast furnace step, most of the cadmium is oxidized and deposited in the blast furnace slag which may later be fumed or discarded. The average controlled emission factor for blast furnaces is 0.063 lb cadmium/ton of lead produced. Emissions are in the form of cadmium oxide. Both companies control their emissions with a baghouse. Total cadmium emissions to the atmosphere from blast furnace operations in 1972 are 12 860 lb (6.43 tons).

Refining. Both electrolytic and chemical precipitation processes are used in Canada. Cadmium is emitted from refining operations in the form of cadmium oxide. Total emissions of cadmium to the atmosphere from this source in 1972 are negligible. This may be explained by the fact that most of the cadmium is retained in the blast furnace slag.

TABLE 2 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM PRIMARY COPPER AND NICKEL SMELTERS

Source	Particle size (microns)	Weight of particulates (%)
Sinter plant	> 74	10
	37 - 74	18
	0.4 - 37	38
	< 0.4	34
Smelter plant A	> 74	19
	37 - 74	26
	0.4 - 37	30
	< 0.4	25
Smelter plant B	> 45	5
	21 - 44	10
	11 - 20	20
	< 10	65
Smelter plant C	44 - 100	5
	10 - 44	20
	< 10	75
Smelter plant D	4.8 - 11.7	19
	2.1 - 4.8	27
	0.5 - 2.1	14
	< 0.5	40

Miscellaneous. Cadmium emissions from activities such as ore preparation, drying and handling are small relative to the other emissions. Depending on the activity, cadmium is emitted either as cadmium sulphide, sulphate or oxide. Total cadmium emissions to the atmosphere from these sources in 1972, are estimated at 178 lb (0.09 ton).

Slag Fuming. At one plant the slag and the baghouse dust from the blast furnace operation are fumed to recover zinc. In this step, zinc is reduced to metal by carbon or carbon monoxide, vaporized, and reoxidized to form a zinc oxide fume which is collected in a baghouse. If collected zinc oxide is relatively pure it may be used as a final product, otherwise it is further treated in a zinc oxide fume leaching plant. Cadmium emissions from the slag fuming operation in 1972 were reported to be 358 lb (0.18 ton).

Zinc Oxide Fume Leaching Plant. Zinc oxide fume from the slag fuming is leached and purified and the zinc is sent for refining by electrolysis (section 2.3). The leach residue is returned to the lead smelter and the purification residue is sent to the cadmium plant in the zinc refinery. The main source of emissions from this process is the solution-cooling vent stack. Small emissions occur from the fume-unloading and acid-thickening vent stack.

Cadmium emissions from the acid thickeners and solution cooling are in the form of cadmium sulphate droplets. Cadmium from fume handling is in the form of cadmium oxide and is controlled with a baghouse. No controls were indicated for acid thickeners and solution cooling. Total emissions of cadmium to the atmosphere from the zinc oxide fume leaching plant in 1972 were 204 lb (0.10 ton).

Total Emissions. The total estimated cadmium emissions to the atmosphere for 1972 from primary lead production are listed in Table 3.

TABLE 3 CADMIUM EMISSIONS FROM PRIMARY LEAD PRODUCTION, 1972

Source	Cadmium emissions (lb)
Sinter	880
Blast furnace	12 860
Refining (anode furnace)	negligible
Miscellaneous	178
Slag fuming	358
Zinc oxide fume leaching plant	204
TOTAL	14 480 (7.24 tons)

Survey results included some source test data as a basis for cadmium emissions information. Some emissions were also based on information from equipment suppliers. There were no other studies found which reported cadmium losses from primary lead production.

2.2.3 *Particle Size Distribution.* Neither of the companies responded with particle size distribution data and no other information was found in the literature.

2.3 Primary Zinc Production

During 1972, 555 200 tons of primary zinc and 1538 tons of cadmium were produced in Canada by four plants.

2.3.1 Process Description. All the primary zinc in Canada is produced by an electrolytic process consisting of:

Roasting. The zinc sulphide ore is roasted to zinc oxide. The roasted ore is termed calcine and contains up to 3% sulphur.

Leaching. The calcine is leached with sulphuric acid to produce a neutral solution of zinc and other metal sulphates. The insoluble portion is separated from the soluble portion and contains about 20% zinc as ferrite, when the conventional electrolytic process is used.*

Purification. Cadmium and other metals are precipitated from the solution and the purified solution is cooled in forced draft cooling towers before going to the electrolysis plant. Arsenic trioxide and zinc dust are usually added to precipitate impurities.

Electrolysis. Zinc is plated from the solution. The temperature of the electrolyte is controlled by forced draft cooling towers.

Melting and Casting. The zinc cathodes are melted and cast into ingots.

Zinc Dust Plant. Zinc dust required for the purification step is made by melting some of the zinc followed by air atomization of the liquid metal.

Cadmium Plant. Cadmium is a by-product of zinc production. It is precipitated from solution during the purification stage and is further purified to remove copper before being melted and cast into ingots.

Figure 5 is a typical flow diagram for a zinc plant.

2.3.2 Emissions. The main cadmium emission sources in the electrolytic zinc process are:

Cadmium Melting Furnace. The average uncontrolled emission factor for the cadmium melting furnace is 0.0018 lb cadmium/ton of zinc produced. None of the companies indicated having any control equipment. Emissions were reported in the form of cadmium oxide. Total cadmium emissions to the atmosphere in 1972 from the cadmium melting furnace were 1028 lb (0.51 ton).

Roaster and Acid Plant. All the primary zinc producers except one have acid plants for the production of sulphuric acid from roaster gases. Before entering the acid plant, the gases are thoroughly cleaned by cyclones, electrostatic precipitators and in some cases acid scrubbers to remove particulate matter. The company without an acid plant has an electrostatic precipitator. Emissions from the acid plants are small and are in the form of cadmium sulphate. Cadmium oxide is emitted from the roaster without an acid plant. Total emissions of cadmium to the atmosphere from this source in 1972 are estimated at 1504 lb (0.75 ton).

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* Two plants in Canada use the Jarosite Process, which gives higher zinc recovery than the conventional method. In the Jarosite Process the insoluble portion contains up to 3% zinc as ferrite.

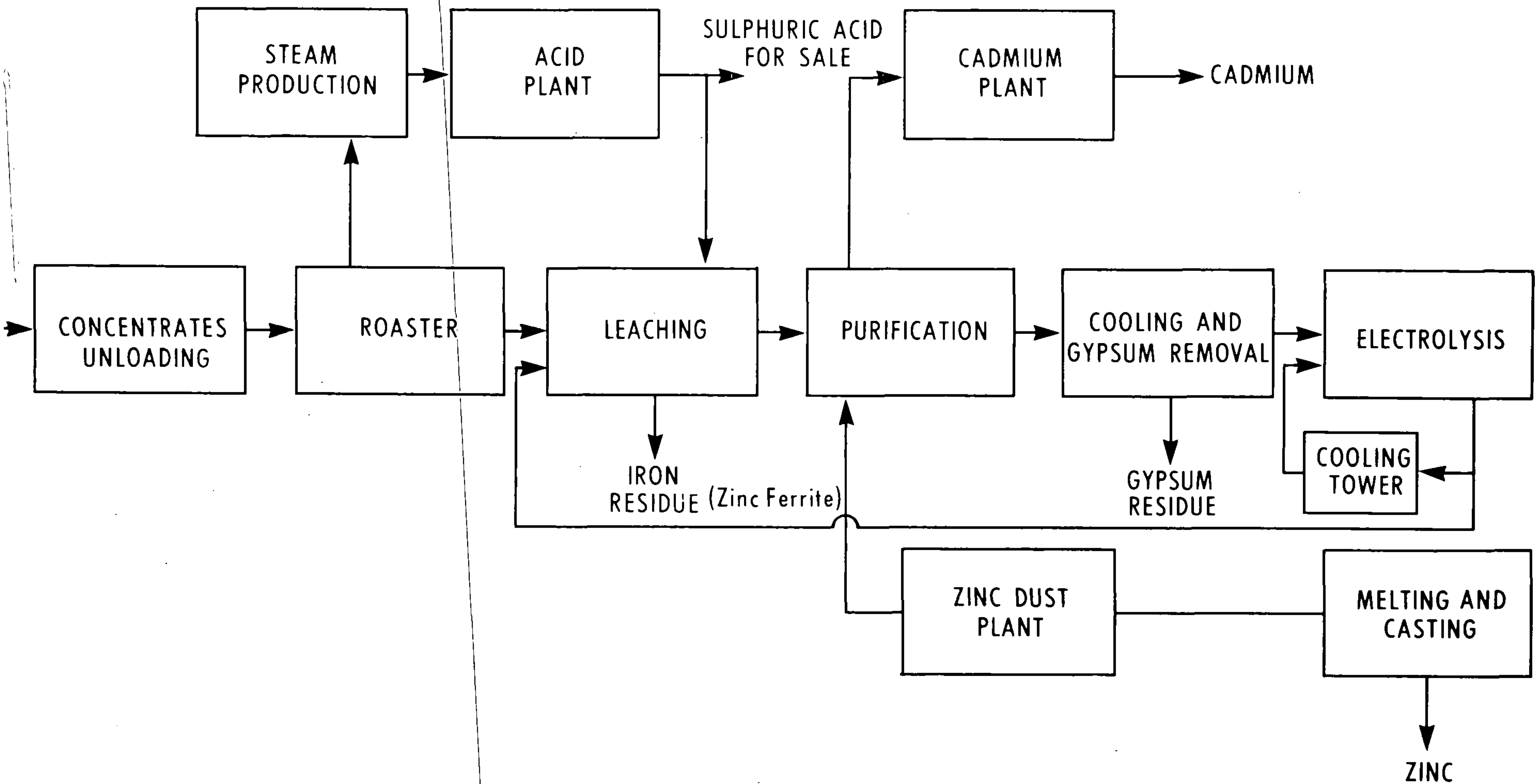

FIGURE 5 PRIMARY ZINC PLANT FLOW DIAGRAM

Ore and Calcine Handling and Storage. Cadmium emissions also occur from ore and calcine handling and storage. A controlled emission factor for these operations was calculated to be 0.00005 lb cadmium/ton of zinc produced. Emissions are controlled with a baghouse and are estimated at 28 lb (0.01 ton) in 1972.

Total Emissions. Total estimated cadmium emissions to the atmosphere for 1972 from primary zinc production are listed in Table 4.

TABLE 4 CADMIUM EMISSIONS FROM PRIMARY ZINC PRODUCTION, 1972

Process stage	Cadmium emissions (1b)
Cadmium melting furnace	1028
Roaster acid plant	1504
Ore and calcine handling and storage	28
TOTAL	2560 (1.3 tons)

There are also trace cadmium emissions from the zinc melting furnace and zinc dust plant.

Most of the companies surveyed reported source test data which were used to estimate cadmium emissions. Some of the information was also based on information from equipment suppliers and on mass balance calculations.

An average uncontrolled emission factor for zinc smelting was estimated at 0.17 lb cadmium/ton of zinc produced. A previous study reports an uncontrolled emission factor of 2 lb cadmium/ton of zinc produced for zinc smelting and refining (13). A possible explanation for the discrepancy may be that the other study was based on interviews rather than on source testing data.

2.3.3 ***Particle Size Distribution.*** The only information reported on particle size distribution is that in Table 5.

TABLE 5 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM PRIMARY ZINC SMELTERS

Source	Particle size (microns)	Weight of particulates (%)
Zinc dross	> 5	27
	< 5	73

2.4 Primary Iron and Steel Production

Forty-five plants in Canada were engaged in the production of primary iron and steel in 1972. Primary iron production capacity was about 12 million tons, and steel furnace plant capacity was about 16 million tons (6).

2.4.1 Process Description. The manufacture of iron and steel comprises some or all of the following steps:

Iron Ore Pretreatment. In certain cases iron ore is treated prior to the blast furnace operation. This process usually involves ore concentration followed by either sintering or pelletizing.

Iron Production. This takes place in the blast furnace. In this process, the iron-bearing materials (iron ore, sinter, pellets, mill scale, iron or steel scrap, etc.), fuel (coke), and flux (limestone and/or dolomite) are charged to the top of the furnace.

Heated air (blast) and, in some instances, fuel (gas, oil or powdered coal) are blown in at the bottom. The blast air burns part of the fuel to produce heat for the chemical reactions involved and for melting the iron, while the balance of the fuel and part of the gas from the combustion remove the oxygen combined with the metal.

A typical blast furnace charge in Canada, per ton of product is:

Ore, Sinter, Pellets	1.6 tons
Coke	0.5 ton
Air	2.0 tons
Limestone/Dolomite	0.1 ton

The product from the blast furnace is known as either hot metal (molten) or pig iron (solid).

The pig iron may be remelted with scrap in cupolas for the production of cast iron.

Steel Production. Blast furnace product and steel scrap are charged to the steel furnace, where further refining takes place. Careful control of contaminants such as silica, phosphorus, sulphur and carbon is necessary to impart the desired mechanical and chemical characteristics to the product steel. Chemical and mechanical properties may be changed by alloying with other metals, such as nickel, chromium and manganese.

The major steel furnaces used in Canada in 1972 were the basic oxygen, the basic open hearth and the electric arc, listed in decreasing order of overall production capacity. Open hearth furnaces are becoming obsolete and should eventually be replaced by basic oxygen furnaces. The availability of cheap hydroelectric power in certain areas may sometimes favour the use of electric furnaces.

Steel Finishing. This includes a large number of operations, depending on the final product. The required product shape may be achieved by casting, or in rolling mills, bar mills or railing mills. Other processes such as scarfing, pickling and galvanizing are employed to achieve the desired surface properties.

2.4.2 Emissions. The main sources of cadmium emissions in primary iron and steel production are blast furnace and steel furnace operations. Some emissions probably also occur from certain pretreatment processes, but these are employed in specialized cases, and emissions are assumed negligible.

Steel Finishing. These operations are conducted at relatively low temperatures where the volatility of cadmium is small. No evidence has been found to indicate that steel finishing is a source of cadmium emissions.

Blast Furnace. The uncontrolled emission factor for this source is estimated at about 2.8×10^{-4} lb cadmium/ton product. Emissions arise principally from volatilization of the cadmium contained in the iron ore.

Steel Furnace. Emissions arise principally from volatilization of the cadmium contained in the scrap metal charged to the furnace. The uncontrolled emission factor is about 0.0018 lb cadmium/ton product; however, there could be considerable variation from plant to plant. This would arise from variation in the cadmium content of scrap steel and the relative quantities of pig iron and scrap in the furnace charge.

Total Emissions. Total estimated cadmium emissions for 1972 from the primary iron and steel industry are listed in Table 6.

Very little cadmium emission data from the primary iron and steel industry were reported in this survey. Emission estimates are based on theoretical emission factors derived from the estimated cadmium content of the principal raw materials (scrap and iron ore). A previous United States survey (4) assumes an uncontrolled emission factor of 0.015 lb/ton of product. This factor was derived by the same method as that used to derive the uncontrolled emission factor for steel production in this report which is estimated at 0.0018 lb/ton; however, United States' statistics indicate a higher cadmium content of scrap steel (4).

TABLE 6 CADMIUM EMISSIONS FROM PRIMARY IRON AND STEEL PRODUCTION, 1972

Process stage	Cadmium emissions (lb)
Iron production and pretreatment	272
Steel production	3881
TOTAL	4153 (2.08 tons)

2.4.3 ***Particle Size Distribution.*** Some companies reported measured particle size data as listed in Table 7.

TABLE 7 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM ELECTRIC STEELMAKING FURNACES

Source	Particle size (microns)	Weight of particulates (%)
Electric furnace	< 5	20-50
	5 - 10	30-50
	10 - 20	10-25
	> 20	5-10
Electric furnace with oxygen lance	0.2 - 5	95

2.5 Specialty Copper Products

Only one company engaged in the production of copper alloys reported using appreciable quantities of cadmium (12.5 tons) as a raw material. As a result, cadmium emissions from this company are substantially higher than those estimated for other producers of copper-based alloys such as brass and bronze.

2.5.1 Process Description. The process is essentially similar to that employed by foundries, the main steps being melting and casting.

Emission estimates are based on data supplied by the company.

A previous study reports a controlled emission factor of 10 lb cadmium/ton cadmium processed for the production of many different brazing alloys and solders (4). Although this study does not give any specific emission factor for the sector under consideration here, it is assumed that both sources can be compared from an emissions viewpoint. The uncontrolled emission factor found in this study is 710 lb cadmium/ton cadmium processed and compares well with the controlled factor of 10 lb/ton found in the other study (4) if one assumes a control efficiency of 98%-99% in the United States.

2.5.2 Emissions. Emissions of cadmium by this company totalled to 8900 lb (4.45 tons) in 1972. No emission control equipment was employed.

2.5.3 Particle Size Distribution. The company reported that 95% of particulate emissions were in the submicron range.

2.6 Iron and Steel Foundries

Total production in Canada in 1972 has been reported at 1 227 541 tons of iron and steel castings (5,6).

2.6.1 Process Description. Scrap iron and steel are melted in different types of furnaces and then cast in molds usually made of sand. Cupola, electric induction and electric arc are the furnace types normally used for melting in iron and steel foundries.

Metals such as cadmium are present as impurities in the furnace charge.

2.6.2 Emissions. Some of the companies responding to this survey have emission control equipment such as cyclones, baghouses or wet caps; however, they provided no reliable emission data. The estimate was based on an uncontrolled emission factor of 0.015 lb cadmium/ton of product, derived from a previous study of particulate and zinc emissions from five Ontario foundries (7) and an analysis of particulate emissions from cupola furnaces (8). The degree of emission control on a provincial basis was estimated internally. A similar survey in the United States (4) estimates the uncontrolled cadmium emission factor for foundries to be 0.015 lb cadmium/ton of process weight which is comparable to the Canadian value.

Total cadmium emissions to the atmosphere in 1972, from iron and steel foundries were estimated at 7295 lb(3.7 tons).

2.6.3 Particle Size Distribution. Information on particle size received from one questionnaire and from an analysis done in the United States on grey iron cupolas is listed in Table 8 (8).

TABLE 8 PARTICLE SIZE DISTRIBUTION FOR PARTICULATE EMISSIONS FROM IRON AND STEEL FOUNDRIES

Source	Particle size (microns)	Weight of particulates (%)
Canadian cupola	0.01 - 0.1	5
	0.1 - 1.0	20
	1.0 - 10.0	75
United States' cupolas	0 - 5	21.2
	5 - 10	6.5
	10 - 20	7.5
	20 - 44	17.4
	> 44	47.4

2.7 Nonferrous Alloys

Products in this group include low-melting-point solders and brazing alloys.

During 1972, 11 companies in Canada processed an estimated 9.5 tons of cadmium. One of the companies surveyed provided emission data. It is estimated that this company accounts for about 55% of total cadmium consumption by this industry.

2.7.1 Process Description. Metals are melted together to produce alloys and then poured into moulds to form bars or ingots. The cadmium content of the alloys varies depending on the product.

2.7.2 Emissions. Significant emissions were reported to have occurred during the melting stage. The amount of emissions varied with the cadmium content of the alloy and the type of kettle used. Cadmium was reported to be emitted as cadmium oxide.

Cadmium emission estimates are based on an average uncontrolled emission factor of 180 lb cadmium/ton cadmium processed. This value was derived from emission data reported by one company in this survey. A previous study reports a controlled emission factor of 10 lb cadmium/ton cadmium processed (4). This is a comparable value if one assumes a control efficiency in the United States of about 94%-95%.

Total uncontrolled cadmium emissions from the production of nonferrous alloys in 1972 are estimated at 1700 lb (0.85 ton).

2.7.3 Particle Size Distribution. There were no data reported in the questionnaires or found in the literature on particle size distribution for nonferrous alloy production.

2.8 Miscellaneous Industrial Sources

The survey identified many operations which process cadmium metal or which introduce cadmium into the process as an impurity in the raw materials.

2.8.1 Cadmium Electroplating. The largest user of cadmium is the electroplating industry which consumed approximately 40 tons of the metal in 1972 (1). The cadmium is purchased as solid balls which are used directly as anodes. The temperature of the electrolyte bath is close to room temperature and no cadmium emissions occur.

2.8.2 Rubber Manufacture. In the rubber industry cadmium is introduced as an impurity in the zinc oxide which is used as an activator for vulcanization and as cadmium activators and accelerators. Cadmium activators and accelerators are not normally used for rubber tires and are used in only very small concentrations in other rubber products. It is assumed that cadmium emissions are based only on zinc emission information from cadmium as an impurity in zinc oxide. Cadmium emissions are estimated at less than 1 lb.

2.8.3 Paint Industry. Approximately 5 tons of cadmium pigments were used in the paint industry in 1972 (10). A personal interview with the Canadian Paint Manufacturers Association revealed that the pigments are usually added from bags into the process and that very little dust is generated (10). Emission control devices, which are seldom used here, are usually baghouses (10). Emissions from the paint industry in 1972 are assumed negligible.

2.8.4 Mining Operations. Because of its close association in nature with zinc, cadmium always occurs in zinc ores and is produced entirely as a by-product of primary zinc production. There were 37 mining companies producing either zinc-bearing ores or concentrates on a regular basis in 1972. The ores and concentrates produced contained 1 402 000 tons of zinc destined for recovery (11).

Based on information received for zinc emissions and an average ratio of cadmium to zinc in the ores of 0.4%, total cadmium emissions to the atmosphere from mining operations in 1972 are estimated at 1120 lb (0.56 ton).

2.8.5 Battery Manufacture. No nickel-cadmium batteries were manufactured in Canada during 1972. Small amounts of cadmium were introduced into dry cell manufacture as impurities in the zinc used for the anodes and in the zinc chloride used in the electrolyte.

Based on 0.008% cadmium content in zinc metal, cadmium emissions from battery manufacture in 1972 are estimated at less than 1 lb.

2.8.6 *Metallurgical Coke Manufacture.* Coal contains minor cadmium impurities, the exact quantity of which varies depending on the source of coal (12). Most of the cadmium present would be volatilized during the coking operation and removed in the scrubbing/cooling towers. It is assumed that negligible quantities are emitted from coal handling.

2.8.7 *Galvanizing.* Cadmium is not used in galvanizing but occurs as an impurity in the zinc metal. Emissions of cadmium from this source in 1972 are assumed negligible.

2.8.8 *Die-Casting.* Cadmium emissions are based on zinc emission data received from the questionnaires. It is assumed that the cadmium and zinc in the emissions are in the same proportion as they are in the zinc metal. Cadmium emissions from die-casting operations in 1972 are therefore estimated at less than 1 lb.

2.8.9 *Zinc Oxide Production.* High-grade zinc is used for the production of zinc oxide with only 0.003% cadmium impurity by weight. Based on zinc oxide emission estimates, cadmium emissions from zinc oxide production in 1972 are estimated to be negligible.

2.8.10 *Vinyl Plasticizers and Stabilizers.* Cadmium is used in the manufacture of vinyl stabilizers and plasticizers. Information from the survey was insufficient for the calculation of an emission factor. A similar survey done in the United States (4) indicates a controlled emission factor of 6 lb cadmium/ton of cadmium processed. It is estimated that approximately 15 tons of cadmium metal went into the manufacture of chemicals, pigments and alloys other than solder (1). Even if all this cadmium went into vinyl plasticizers and stabilizers, total cadmium emissions would be only 90 lb (0.05 ton) based on the United States' emission factor.

2.8.11 *Brass and Bronze Foundries.* Cadmium is not normally used as a raw material in brass and bronze foundries but occurs as an impurity in the zinc metal. No cadmium emission data were reported in the questionnaires. Replies to questionnaires gave an average ratio of cadmium to zinc in the zinc metal of 0.008%. It is assumed that emissions of these elements are in the same ratio. Based on data received for zinc emissions, cadmium emissions from brass and bronze foundries in 1972 are estimated at 40 lb (0.02 ton).

2.8.12 *Pigment Production.* Cadmium is used in the production of paint pigments. The quantity manufactured in Canada in 1972 was small and emissions are assumed to be negligible.

2.8.13 *Petroleum Refining.* Data received in this study provided no evidence to indicate that cadmium is discharged to the atmosphere during the refining process; however, cadmium is found in a number of products such as diesel oils, light oils, motor oils and heavy oils. When these oils are subsequently burned as fuels, it is likely that the cadmium is discharged with the combustion products. These emissions are described in sections 3 and 4.

2.8.14 ***Phosphate Fertilizers.*** Most of the phosphate rock used for phosphate fertilizer production is imported from the United States. Although these fertilizers contain some cadmium, the concentrations are low and the potential emissions from their use are assumed to be negligible.

2.8.15 ***Cigarette Smoking.*** Cadmium is known to be present in minute amounts in tobacco. An American study (13) gives an emission factor of 16.0 μg cadmium/20 cigarettes consumed, based on the analysis of 15 samples by a colorimetric technique. Although the tobacco used for cigarette-making may sometimes differ slightly in Canada, it is thought that the American factor is still applicable for the purpose of this inventory.

About 52 500 million cigarettes were produced in Canada in 1972. The consumption of these cigarettes led to the release of 93 lb of cadmium to the atmosphere.

Cadmium emissions from miscellaneous sources are summarized in Table 9.

3 EMISSIONS FROM FUEL COMBUSTION - STATIONARY SOURCES

Stationary sources can be divided into the following categories:

- Power generation
- Industrial and commercial
- Domestic

The five principal fuel types used are gaseous (natural gas, propane, etc.) diesel oils, light oils, heavy oils and coal. Of these only the gaseous fuels do not contain cadmium.

Emission factors used for these fuels are based on reports by the U.S. Environmental Protection Agency (13,4), and are listed in Table 10.

Emission factors could not be developed specifically for Canadian conditions because of a lack of proper data at the time this survey was compiled. However, the cadmium content of heavy oil was reported in two replies to the survey as being 5.0 and 2.1 ppm. This compares favorably with the related United States' emission factor which is based on a cadmium content of 4.8 ppm. It is hoped that data will be available in the near future to enable the development of emission factors specific to Canadian conditions.

3.1 Power Generation

In 1972, electricity generated by coal-fuelled facilities accounted for 62% of total thermal generation; petroleum fuels were responsible for 10%, natural gas for 15.7% and nuclear fuels for 12.3%.

Estimated cadmium emissions from power generating stations in 1972 are listed in Table 11. It is estimated that coal-fuelled generating stations have control equipment averaging 88% efficiency whereas facilities fuelled with heavy oil are almost totally uncontrolled.

TABLE 9 CADMIUM EMISSIONS FROM MISCELLANEOUS SOURCES, 1972

Source	Cadmium emissions (lb)
Cadmium electroplating	0
Rubber manufacture	< 1
Paint industry	negligible
Mining operations	1120
Battery manufacture	< 1
Metallurgical coke manufacture	negligible
Galvanizing	negligible
Die-casting	< 1
Zinc oxide production	negligible
Vinyl plasticizers and stabilizers	90
Brass and bronze foundries	40
Pigment production	negligible
Petroleum refining	0
Phosphate fertilizers	negligible
Cigarette smoking	93
TOTAL	1343 (0.67 ton)

Approximately 60% of the emissions occur during the winter months (14), depending on climate and the extent to which electricity is used for heating.

3.2 Industrial and Commercial Fuels

Approximately 22 million barrels of diesel oil, 6.5 million barrels of light fuel oil, 90 million barrels of heavy oils and 2.7 million tons of coal were consumed for industrial and commercial purposes

TABLE 10 CADMIUM EMISSION FACTORS FOR FUELS

Fuel	Cadmium emission factor (uncontrolled)
Light oil	0.0035 lb cadmium/1000 imp. gal.
Diesel oil	0.0007 lb cadmium/1000 imp. gal.
Heavy oil	0.048 lb cadmium/1000 imp. gal.
Coal	0.005 lb cadmium/ton coal

TABLE 11 CADMIUM EMISSIONS FROM POWER GENERATION, 1972

Source	Cadmium emissions (lb)
Diesel oil facilities	27
Light fuel oil facilities	12
Heavy oil facilities	15 586
Coal facilities	10 198
TOTAL	25 823 (12.91 tons)

in Canada during 1972. The figure of 2.7 million tons of coal does not include coal used for coke manufacture (section 2.8).

Estimated cadmium emissions resulting from the industrial and commercial combustion of fuels during 1972 are listed in Table 12.

The degree of emission control is assumed to be insignificant for oil combustion and averages about 80% for coal combustion for industrial purposes (17).

Emissions of cadmium from this source increase in the winter as the fuels are also used for heating.

TABLE 12 CADMIUM EMISSIONS FROM INDUSTRIAL AND COMMERCIAL FUEL USE, 1972

Source	Cadmium emissions (lb)
Diesel oil combustion	497
Light oil combustion	818
Heavy oil combustion	147 715
Coal combustion	2 705
TOTAL	149 735 (74.87 tons)

3.3 Domestic Fuels

Light oils are generally used for domestic heating. A small quantity of heavy oils is used, mainly in apartment complexes.

Approximately 81 million barrels of light fuel oil and 3 million barrels of heavy oil were used for domestic heating in 1972.

It is assumed that there are no emission controls as these fuels are burned solely in homes and apartments. The emissions occur mainly in the winter months (October - April).

TABLE 13 CADMIUM EMISSIONS FROM DOMESTIC FUEL USE, 1972

Source	Cadmium emissions (lb)
Light fuel combustion	9 902
Heavy oil combustion	5 126
TOTAL	15 028 (7.51 tons)

4 EMISSIONS FROM TRANSPORTATION SOURCES

Transportation is considered under four headings:

- Motor vehicles
- Rail transport
- Shipping
- Aviation

4.1 Motor Vehicles

Motor vehicles use either gasoline or diesel oil as a fuel, and only the latter contains cadmium (section 3). Motor oil also contains minor amounts of cadmium (4, 13).

Approximately 2 million barrels of diesel oil were purchased for motor vehicles in Canada in 1972 (15). Emissions from diesel oil use were estimated using an uncontrolled emission factor of 0.0035 lb/1000 imperial gallons (section 3).

Emissions from motor oil were estimated using an emission factor of 0.002 lb/10^6 vehicle miles (13).

Emissions of cadmium from motor vehicles in 1972 are listed in Table 14.

Emissions are slightly higher during the summer months due to higher vehicle use for recreational purposes.

TABLE 14 CADMIUM EMISSIONS FROM MOTOR VEHICLES, 1972

Source	Cadmium emissions (lb)
Diesel oil combustion	279
Motor oil combustion	233
TOTAL	512 (0.26 ton)

4.2 Rail Transport

Rolling stock uses diesel oil which contains cadmium (section 3). Although railway companies purchase heavy oils and coal, these are employed for heating and power generation and the emissions are consequently dealt with in section 3 of this report.

Approximately 13 million barrels of diesel oil were purchased by railway companies in Canada in 1972 (15). Emissions were estimated using an uncontrolled emission factor of 0.0035 lb cadmium/1000 imperial gallons (section 3).

Emissions from rail transport in 1972 are estimated at 1657 lb (0.83 ton).

4.3 Shipping

Shipping uses diesel oil, and bunker oil, both of which contain cadmium (section 3.1). It is estimated that only 20% of the diesel oil and bunker oil are burned within Canadian territory. The remainder, which is burned on the high seas, is not included in this inventory.

Approximately 7 million barrels of diesel oil were purchased for shipping operations in Canada in 1972 (15). Emissions from this source were calculated using an emission factor of 0.0035 lb cadmium/1000 imperial gallons (section 3). Approximately 11 million barrels of bunker oil were purchased in Canada in 1972 for shipping (15). Emissions were estimated using an emission factor of 0.048 lb cadmium/1000 imperial gallons (section 3).

Emissions are substantially reduced during winter months when some inland waterways are closed.

Emissions of cadmium from shipping operations in Canada for 1972 are listed in Table 15.

4.4 Aviation

Aircraft are fuelled with either aviation gasoline or kerosene, neither of which contain significant quantities of cadmium. Cadmium emissions are assumed to be negligible.

TABLE 15 CADMIUM EMISSIONS FROM SHIPPING, 1972

Source	Cadmium emissions (lb)
Diesel oil combustion	73
Bunker oil combustion	3739
TOTAL	3812 (1.91 tons)

4.5 Tire Wear

Zinc oxide is used extensively in tire manufacture as an activator in the vulcanization process and to protect the tire against ultraviolet attack. Cadmium is present as an impurity in the zinc oxide. As the tire wears, fine particles of rubber containing zinc oxide and cadmium are emitted.

Questionnaire replies permitted an estimate of the average zinc oxide content of tires of 38 lb/ton of rubber, and a cadmium/zinc ratio of 0.0078%. On average, 0.918 lb rubber are emitted per vehicle per 1000 miles travelled (16).

Other information used was the number of motor vehicles registered in 1972, by type of vehicle, and the assumption that cars travel 12 000 miles per year, trucks about 20 000 miles per year, and motorcycles 4000 miles per year.

Even though tire wear may be 50% more during the winter months (16) the large volume of vacation traffic in the summer would probably offset this. Therefore, seasonal variations are likely to be small.

It is estimated that 142 lb (0.07 ton) of cadmium were emitted from this source in 1972.

Total estimated cadmium emissions to the atmosphere for 1972 from the transportation sector are listed in Table 16.

5 EMISSIONS FROM SOLID WASTE INCINERATION

In 1972, approximately 1.4 million tons of refuse were disposed of in 17 municipal incinerators (17), and about 134 000 tons of sewage sludge were incinerated in three cities (18).

TABLE 16 CADMIUM EMISSIONS FROM TRANSPORTATION SOURCES, 1972

Source	Cadmium emissions (lb)
Motor vehicles	512
Rail transport	1657
Shipping	3812
Aviation	negligible
Tire wear	142
TOTAL	6123 (3.06 tons)

A previous study indicates that the uncontrolled cadmium emission factor for solid waste incinerators is about 5.3 x 10^{-3} lb/ton of refuse burned (13). Based on this factor it is estimated that about 2840 lb (1.42 tons) of cadmium were discharged to the atmosphere during 1972 from municipal solid waste incinerators. The same study (13) indicates an uncontrolled cadmium emission factor for sewage sludge incinerators of about 4.7 x 10^{-2} lb/ton of sewage sludge burned. Based on this factor it is estimated that about 4835 lb (2.42 tons) of cadmium were discharged to the atmosphere during 1972 from municipal sewage sludge incinerators.

6 EMISSIONS FROM PESTICIDE APPLICATION

The total quantity of pesticides containing cadmium sold in Canada in 1972 is estimated at 6300 lb.

When considering the air emissions resulting from the use of pesticides it is very important to delineate the parameters that determine the percentage 'drift' (drift being the amount of pesticide leaving the target area). Factors that affect drift are droplet size of the liquid, wind speed, temperature, foliage density, humidity, and operator skill.

Pesticide application is dependent upon chemical makeup and desired effect. Aerial application is used for treatment of large areas such as forests. Fruit tree spraying is usually from the operator upward whereas spraying of vegetable crops is from the operator downward. Fogging is used in certain cases that can take advantage of drifting. Pesticides are usually applied during June and July.

Losses during aerial application can range from 10%-50% depending on the factors mentioned above. In fruit tree spraying the air emission may be 50% early in the season when the leaves are small. Other types of application have an average loss of about 10% (19). Estimated losses of pesticide during application were obtained from personal communications with specialists in the field (19,20). No previous studies on this topic were found.

Since pesticides containing cadmium are usually organic or inorganic salts, there is no loss by volatilization (19).

Cadmium emissions to the atmosphere from pesticide application are estimated at about 70 lb (0.04 ton) in 1972.

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APPENDIX - SURVEY OF QUESTIONNAIRE RETURNS AND QUALITY INDEX

Sector	No. of questionnaires Sent	Returned	Rate of response (%)	Quality index of questionnaires returned* 1	2	3	4	5	Average quality index
Primary copper & nickel & assoc.	13	12	92	-	-	-	4	8	4.7
Primary iron & steel	45	28	62	2	2	5	7	12	3.9
Primary aluminum	6	6	100	-	-	-	-	6	5.0
Primary lead & zinc	6	6	100	-	-	-	-	6	5.0
Copper, brass & bronze foundries	84	27	32	2	4	7	8	6	3.4
Die-casting	91	51	56	4	18	14	10	5	2.9
Iron & steel foundries	194	88	45	10	16	25	24	13	3.2
Metallurgical coke	7	3	43	-	-	1	-	2	4.7
Phosphate fertilizers & elemental phosphorus	31	28	90	-	1	13	2	12	3.9
Galvanizing	46	26	57	2	3	10	10	1	3.2
Plating	83	25	30	7	9	3	6	-	2.3
Ferroalloys & assoc.	13	4	31	-	-	-	1	3	4.8
Pesticides	58	26	45	9	10	-	4	3	2.3
Ceramics and glass	105	44	42	1	8	6	18	11	3.7
Nonferrous alloys	20	11	55	1	2	-	5	3	3.6
Battery mfg.	5	2	40	-	-	-	1	1	4.5
Rubber mfg.	24	20	83	-	2	5	7	6	3.9
Zinc oxide mfg.	2	1	50	-	-	-	-	1	5.0
Mining	39	21	54	2	2	4	5	8	3.7
Porcelain & enamels	30	17	57	4	4	4	3	2	2.7
Clay products mfg.	57	21	37	7	4	3	4	3	2.6
Petroleum refining	47	35	74	4	5	11	-	15	3.5
Vinyl stabilizers & plasticizers	13	8	62	-	-	2	3	3	4.1
Welding rods mfg.	12	10	83	2	2	-	2	4	3.4
Miscellaneous	16	13	81	-	-	4	3	6	4.2
TOTAL	1047	533	51	57	92	117	127	140	3.4

* A Quality Index of Questionnaires returned was based on the following rating:

1. No emissions reported, no back-up given
2. No pertinent information
3. Poor reply, data insufficient
4. Medium reply, emissions can be calculated
5. Good reply, emissions data given and documented