This report is a combination of three reports:

1. CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE #2, Prepared by Athena Sustainable Materials Institute, Ottawa, Canada, 2005;

2. CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE, Prepared by Venta, Glaser & Associates, Ottawa, Canada, October 1999;

   and

3. RAW MATERIAL BALANCES, ENERGY PROFILES AND ENVIRONMENTAL UNIT FACTOR ESTIMATES: **CEMENT AND STRUCTURAL CONCRETE PRODUCTS**, Prepared by Canada Centre for Mineral & Energy Technology and Radian Canada Inc., Ottawa, Canada, October 1993.

CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE #2

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For:
CEMENT ASSOCIATION OF CANADA

Ottawa, Canada
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CONTENTS

CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE #2

1 Introduction

In 1998, Venta, Glaser & Associates was commissioned by the Athena Institute to prepare an addendum to the October 1993 report entitled *Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Cement and Structural Concrete Products*. The purpose was to take account of changes in the structure and environmental performance of the Canadian cement and concrete industries in the years since the original report was issued. The original 1993 report was based primarily on 1991 data whereas the addendum relied on 1997/98 data. This second addendum was commissioned by the Cement Association of Canada and was completed by the Athena Institute in 2005 relying on 2004 data

Like the 1998, this second addendum follows the structure of, and should be used in conjunction with, the original 1993 report. In instances where the 1998 addendum introduced information not contained in the original 1993 report, we have elected to retain this information in this new addendum, thus the 1998 addendum is not required for the user to follow the update procedure or results[1] herein.

Part I deals with cement production and Part II with production of the various structural concrete products used in buildings. Other than a few explanatory notes, the material provided here is in the mainly in the form of tables that replace corresponding tables in the original report. Except where noted, the original report still provides the descriptive and analytical material essential to understanding the industry and the various life cycle inventory estimates.

2 Part I: Cement Production

The cement data were revised according to information for 2004 provided by G. Venta of the Cement Association of Canada, supplemented by "Cement 2004" statistics from the Canadian Minerals Yearbook (final draft). The update data therefore represents the situation in the Canadian cement industry in 2004. Full references are given under Table 2.1 which follows the Part I explanatory notes.

The main differences between the data provided here and in the original 1993 and 1998 addendum report reflect either shifts in the relative production of the plants in the respective regions, a shift in kiln technologies employed or the addition and closure of some older wet kilns or complete plants in some regions. The revised tables are

[1] For those wishing to better understand the effects of capacity utilization on the derivation of the inventory estimates, the 1998 addendum provides an excellent discussion.

numbered the same as the corresponding tables in the original report and only tables that were changed are included in this addendum.

One important difference between industry operations since the original report is capacity utilization - increasing from about 59.2% in 1991 to 96% in 1997 and falling to 87% utilization in 2004. This difference mainly affected the estimates of emissions to water from quarry operations, storm water run-off, and cement plant operations. The absolute amounts of these emissions are all relatively independent of capacity utilization, but the inventory results are expressed per unit of finished cement output which is obviously a direct function of capacity utilization.

Following are brief explanations of the changes to specific sections and tables in the original report related to cement production. The headings indicate the sections in the1993 report to which the notes refer. The revised tables follow the explanatory notes and have the same table numbers as in the original report.

2.1 Original Section 2

Table 2.1 was revised, reflecting the 2004 manufacturing and capacity situation in the Canadian cement industry. Significant changes in the industry since the 1998 update include:

- The closure of two wet kilns at Lafarge's Richmond facility which have been replaced with a larger capacity precalciner kiln technology;
- The closure of the cement plant in Corner Brook, NF by Lafarge;
- The addition of a new kiln at Federal White's Woodstock facility; and,
- A general shift across the industry back to the use of coal in place of natural gas as the primary fuel used to fire the kilns.

2.2 Original Section 3

Raw materials requirements and transportation in Tables 3.1 and 3.2 are unchanged. No direct information from the plants was solicited and we assumed no change in raw material input types.

2.3 Original Section 4

All energy input tables, i.e. 4.1 to 4.3 and 4.5 to 4.10 were revised taking into consideration basic changes in the industry, including relative shifts in market contributions among the plants (which affect weighted regional averages), the closure of some older wet kilns (Lafarge, Richmond plant), the addition of new capacity (Lafarge, Richmond and Federal White, Woodstock) and the closure of one complete plant (Lafarge, Corner Brook, NF).

The changes in the West Coast are significant due to changes in both technology employed and relative contributions by the operations. Changes in Alberta (Prairie region) are relatively small, reflecting only minor shifts in relative contributions of various operations and marginal increases in reported kiln capacities. In Ontario (Central region) plant utilization was down slightly and white cement manufacture now accounts for 11% of the regions capacity up from 5% in 1998. The closure of the Corner Brook plant in the East region resulted in reduced manufacturing energy inputs (Tables 4.2-4.3).

We did not change Table 4.4, which shows manufacturing energy use estimates from various sources. However, the fuel efficiency of clinker production, which excludes electrical energy for clinker/gypsum grinding, dropped to 3.66 GJ/tonne of production in 2004 from 3.8 GJ/tonne in 1997/98.

Transportation distances/modes (Table 4.5) and resulting transportation energy for finished cement (Table 4.6) were slightly changed as a result of the changes in industry structure.

Tables 4.7-4.10 summarize the revised energy inputs.

2.4 Original Section 5

Changes in energy inputs cascade through and affect the emissions to air associated with cement production. As before, emissions due to electrical power usage are excluded because the Athena software assigns these according to the particular grid relevant to the region/city under consideration.

Tables 5.1-5.7 and 5.10-5.11 give revised estimates of emissions to air for various steps in cement production, from resource extraction to finished product transportation. CO_2, NO_x and SO_x emission estimates take account of calcination CO_2, thermal/prompt NO_x and retained sulfur in the same manner and using the same assumptions as in the original study (Tables 5.5-5.7).

We did not change the NOx emission matrix (Table 5.8) for various types of cement kilns vs. different fossil fuels. We also assumed that the particulate emission factors (Table 5.9) remained the same because all the cement plants had already installed modern particulate collection systems before 1990 and continue to collect virtually all of their particulate emissions.

2.5 Original Section 6

Both Tables 6.1 and 6.2 were revised, with the differences between 1997 and 2004 cement industry capacity utilization resulting in modest reductions in the emissions to water expressed in g/tonne of finished cement (Table 6.1).

2.6 Original Section 7

Table 7.3 was modified to reflect the shifts in the industry from the older wet kilns to more modern processes. In addition, more cement kiln dust (CKD) is being both stockpiled and utilized. While we did not survey the industry, CAC[2] provided a new estimate of cement kiln dust waste for the industry which we integrated into the report

[2] Estimate provided by G. Venta, CAC (December, 2005)

(previously CKD waste was estimated to be in the order of 27% of the total CKD produced, waste is now estimated to be 15% of the total production of CKD).

2.7 Original Section 8

In the original report, this section provided a summary by simply showing the key tables from all of the preceding sections. Since the revised tables are presented here in sequence without intervening text, a repeat of the original summary section is unnecessary.

2.8 Revised Tables

TABLE 2.1
2004 CANADIAN CEMENT PLANT LOCATIONS, KILN TYPES, KILN CAPACITIES AND OTHER EQUIPMENT

	Kilns (1,000t/y)				**Grinding equipment**		
Company and Location	Wet	Long Dry	Pre-heater	Pre-calciner	Roller mills	High efficiency separators	Roller presses
Tilbury Cement Ltd.			1116		1	2	
Delta, BC							
Lafarge Canada Inc.				1059		2	
Richmond, BC							
Lafarge Canada Inc.		209					
Kamloops, BC							
Lafarge Canada Inc.		456					
Exshaw, AB				841			
Inland Cement Ltd.				992	1		
Edmonton, AB							
St Marys			653		1		1
St. Mary, ON							
Federal White Cement Ltd		929				1	1
Woodstock, ON							
Lafarge Canada Inc.	547						
Woodstock, ON							
St. Lawrence Cement Inc.				1883		1	
Mississauga, ON							
St Marys.				1966	1	1	
Bowmanville, ON							
ESSROC Canada Inc.		279			2		
Picton, ON			837				
Lafarge Canada Inc.			1010			2	
Bath, ON							
Lafarge Canada Inc.		956					
St. Constant, PQ							
St. Lawrence Cement Inc.		900				1	
Joliette, PQ							
Climent Quebec Inc.				854	1		1
St. Basile, PQ							
Lafarge Canada Inc.		486					
Brookfield, NS							
Capacity Total: 15,973	**1,666**	**4,215**	**3,616**	**6,536**			

Source: 1)"Cement 2004", Canadian Minerals Yearbook (final draft), NRCAN 2005.
2) Athena™ "Cement and Structural Concrete Products", Ottawa, 1993 and updated in 1998.

Table 4.1
Weighted average energy use for raw materials extraction and transport
[GJ/tonne of finished cement]

Region	Extraction	Raw materials transportation				
	Diesel - road	Diesel - road	Diesel - rail	HFO - marine	Electricity	Total Transport
West Coast	0.04468	0.01100	0.00044	0.08236	0.00038	0.09418
Prairie	0.04455	0.03498	0.19704	0.00000	0.00075	0.23277
Central	0.04439	0.03412	0.00458	0.02799	0.00217	0.06886
East	0.04408	0.01305	0.00000	0.00788	0.00132	0.02225
Canada	0.04440	0.02658	0.03063	0.02807	0.00153	0.08680

Table 4.2
Weighted average energy use in manufacturing by process step
[GJ/tonne of finished cement]

Region	Process Step					
	Primary Crushing	Secondary Crushing	Raw Grinding	Pyro-processing	Finish Grinding	Total Manufacturing
West Coast	0.01782	0.03574	0.32905	3.33094	0.17595	3.88949
Prairie	0.01782	0.03564	0.33299	3.67729	0.20880	4.27254
Central	0.01776	0.03551	0.34547	3.74197	0.19287	4.33358
East	0.01763	0.03527	0.35181	4.62433	0.19435	5.22339
Canada	0.01775	0.03551	0.34250	3.84790	0.19292	4.43659

Table 4.3
Weighted average energy use in manufacturing by energy form
[GJ/tonne of finished cement]

Region	Energy Form					
	Nat. Gas	Coal	Oil	Coke	Waste	Electricity	Total
West Coast	**0.75453**	**2.18906**	**0.00000**	**0.16269**	**0.17645**	**0.60676**	3.88949
Prairie	**0.68319**	**2.61158**	**0.00000**	**0.33774**	**0.00000**	**0.64003**	4.27254
Central	**0.69827**	**1.62356**	**0.21274**	**0.99991**	**0.18108**	**0.61803**	4.33358
East	**0.42080**	**1.71171**	**0.06941**	**1.14711**	**1.27667**	**0.59769**	5.22339
Canada	**0.64899**	**1.97175**	**0.19153**	**0.70495**	**0.30394**	**0.61543**	4.43659

Table 4.5
Weighted average transportation distances and modes for finished cement
[km/tonne]

Region / City	Distance by Mode: Truck	Rail	Ship
West Coast			
Vancouver	89.80		
Prairie			
Calgary	309.90		
Winnipeg		2620.00	
Central			
Toronto	175.76		173.24
East			
Montreal	123.42	40.00	
Halifax	184.20		

Table 4.6
Weighted average transportation energy for finished cement
[GJ/tonne]

Region / City	Energy Form: Diesel - road	Diesel - rail	HFO marine	Total
West Coast				
Vancouver	0.10596			0.10596
Prairie				
Calgary	0.36568			0.36568
Winnipeg		1.28380		1.28380
Central				
Toronto	0.20737		0.00208	0.209477
East				
Montreal	0.14564	0.00196		0.14760
Halifax	0.21736			0.21736

Table 4.7
Weighted average energy use in cement production by process stage
[GJ/tonne of finished cement]

Region / City	Process Stage: Raw Materials Extraction	Raw Materials Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.04468	0.09418	3.88949	0.10596	4.13431
Prairie					
Calgary	0.04455	0.23277	4.27254	0.36568	4.91554
Winnipeg	0.04455	0.23277	4.27254	1.28380	5.83366
Central					
Toronto	0.04439	0.06886	4.33358	0.209477	4.65631
East					
Montreal	0.04408	0.02225	5.22339	0.14760	5.43732
Halifax	0.04408	0.02225	5.22339	0.21736	5.50708

Table 4.8
Weighted average energy use in cement production by process stage
[%]

Region / City	Raw Materials Extraction	Raw Materials Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	1.08	2.28	94.08	2.56	100.00
Prairie					
Calgary	0.91	4.74	86.92	7.43	100.00
Winnipeg	0.76	3.99	73.24	22.01	100.00
Central					
Toronto	0.95	1.48	93.07	4.50	100.00
East					
Montreal	0.81	0.41	96.07	2.71	100.00
Halifax	0.80	0.40	94.85	3.95	100.00

Table 4.9
Weighted average pyroprocessing energy by process type

Process type	GJ/tonne
Wet	5.91889
Dry Long	5.09860
Dry Preheater	3.36187
Dry Precalciner	3.25748

Table 4.10
Weighted average energy use in cement production by energy form
[GJ/tonne of finished cement]

Region	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	TOTAL
West Coast										
Vancouver	0.16164	0.00044	0.08236	0.75453	2.18906	0.00000	0.16269	0.17645	0.60714	**4.13432**
Prairie										
Calgary	0.44521	0.19704	0.00000	0.68319	2.61158	0.00000	0.33774	0.00000	0.64078	**4.91554**
Winnipeg	0.07953	1.48084	0.00000	0.68319	2.61158	0.00000	0.33774	0.00000	0.64078	**5.83366**
Central										
Toronto	0.28591	0.00458	0.03007	0.69827	1.62356	0.21274	0.99991	0.18108	0.62020	**4.65631**
East										
Montreal	0.20277	0.00196	0.00788	0.42080	1.71171	0.16348	1.07770	1.25202	0.59901	**5.43732**
Halifax	0.27449	0.00000	0.00788	0.42080	1.71171	0.16348	1.07770	1.25202	0.59901	**5.50708**

Table 5.1
Energy emissions factors
[kg/GJ]

	CO2	SO2	NOx	VOC	CH4	CO
natural gas	49.700	0.0002	0.0590	0.00120	0.00130	0.01500
diesel road	70.700	0.1020	0.8070	0.08690	0.02170	0.44300
diesel rail	70.700	0.1020	1.4000	0.07000	0.00780	0.05700
H.F. oil marine	74.000	0.4500	0.2000	0.36000	0.04000	0.00740
H.F.oil industr.	74.000	0.8375	0.1600	0.00290	0.00082	0.01440
coal - W.Coast	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
coal - Prairie	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
coal - Central	87.600	0.8360	0.2500	0.00150	0.00054	0.09300
coal - East	85.333	1.7278	0.2500	0.00150	0.00054	0.09300
coke	86.000	1.1500	0.2400	0.00140	0.00051	0.08800
waste	67.500		0.1200	0.00120	0.00110	

Table 5.2
Atmospheric emissions due to cement raw materials extraction
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	3158.88	4.56	36.06	3.88	0.97	19.79	843.20
Prairie	Calgary	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
	Winnipeg	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
Central	Toronto	3138.37	4.53	35.82	3.86	0.96	19.66	840.02
East	Montreal	3116.46	4.50	35.57	3.83	0.96	19.53	833.44
	Halifax	3116.46	4.50	35.57	3.83	0.96	19.53	833.44

Table 5.3
Atmospheric emissions due to cement raw materials transportation
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO
West Coast	Vancouver	6903.45	38.23	25.97	30.64	3.54	5.51
Prairie	Calgary	16403.81	23.67	304.08	16.83	2.30	26.73
	Winnipeg	16403.81	23.67	304.08	16.83	2.30	26.73
Central	Toronto	4807.35	16.54	39.54	13.36	1.90	15.58
East	Montreal	1505.76	4.88	12.11	3.97	0.60	5.84
	Halifax	1505.76	4.88	12.11	3.97	0.60	5.84

Table 5.4
Atmospheric emissions due to cement manufacturing
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	768165.70	44.67	4525.61	4.63	2.44	229.22	483.06
Prairie	Calgary	807606.96	59.69	5016.32	5.21	2.47	282.85	938.00
	Winnipeg	807606.96	59.69	5016.32	5.21	2.47	282.85	938.00
Central	Toronto	789220.09	104.23	2074.99	5.51	2.67	252.52	340.32
East	Montreal	854604.78	168.18	2979.57	6.56	3.53	262.69	863.23
	Halifax	854604.78	168.18	2979.57	6.56	3.53	262.69	603.00

Table 5.5
Fuel and calcination CO_2 emissions from cement manufacturing
[g/tonne of cement]

Region	City	Calcination CO2	Fuel Manufact. CO2	Total Manufact. CO2	Calcination as% of Total Manufact. CO2	Grand Total CO2
West Coast	Vancouver	498334.83	269830.87	768165.70	64.87	785719.40
Prairie	Calgary	498334.83	309272.13	807606.96	61.71	853014.03
	Winnipeg	498334.83	309272.13	807606.96	61.71	917925.12
Central	Toronto	498334.83	290885.26	789220.09	63.14	811982.70
East	Montreal	498334.83	356269.95	854604.78	58.31	869662.31
	Halifax	498334.83	356269.95	854604.78	58.31	874594.06

Table 5.6
SO_2 cement manufacturing emissions corrected as per Gagan
[g/tonne of cement]

Region	City	Pyroproces. Fuel SO2	Corrected Pyroproses. SO2	Corrected Ttl. Manufact. SO2	Corrected Grand Total SO2
West Coast	Vancouver	1105.77	44.64	44.67	98.26
Prairie	Calgary	1477.94	59.66	59.69	125.20
	Winnipeg	1477.94	59.66	59.69	218.85
Central	Toronto	2581.27	104.20	104.23	147.39
East	Montreal	4165.58	168.15	168.18	192.61
	Halifax	4165.58	168.15	168.18	199.73

Table 5.7
NOx cement manufacturing emissions
[g/tonne of cement]

Region	City	Pyroprocess. NOx	Fuel NOx	Thermal and Prompt NOx	Total Manufact. NOx	Grand Total NOx
West Coast	Vancouver	4517.73	643.33	3874.40	4526.41	4673.94
Prairie	Calgary	5007.33	765.39	4241.95	5016.21	5651.35
	Winnipeg	5007.33	765.39	4241.95	5016.21	7153.56
Central	Toronto	2065.60	733.34	1332.27	2075.10	2318.25
East	Montreal	2969.47	877.99	2091.48	2979.28	3147.24
	Halifax	2969.47	877.99	2091.48	2979.28	3202.37

Table 5.10
Atmospheric emissions due to transportation of finished cement
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO
West Coast	Vancouver	7491.37	10.81	85.51	9.21	2.30	46.94
Prairie	Calgary	25853.58	37.30	295.10	31.78	7.94	162.00
	Winnipeg	90764.66	130.95	1797.32	89.87	10.01	73.18
Central	Toronto	14816.89	22.09	167.79	18.77	4.58	91.89
East	Montreal	10435.32	15.06	120.28	12.79	3.18	64.63
	Halifax	15367.07	22.17	175.41	18.89	4.72	96.29

Table 5.11
Total atmospheric emissions due to cement production
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	**785,719**	**98.26**	**4673.94**	**48.36**	**9.25**	**301.46**	**1326.26**
Prairie	Calgary	**853,014**	**125.20**	**5651.35**	**57.69**	**13.67**	**491.31**	**1779.50**
	Winnipeg	**917,925**	**218.85**	**7153.56**	**115.78**	**15.75**	**402.49**	**1779.50**
Central	Toronto	**811,983**	**147.39**	**2318.25**	**41.50**	**10.11**	**379.66**	**1180.34**
East	Montreal	**869,662**	**192.61**	**3147.24**	**27.15**	**8.26**	**352.69**	**1696.67**
	Halifax	**874,594**	**199.73**	**3202.37**	**33.25**	**9.80**	**384.35**	**1436.44**

Table 6.1
Liquid Effluent due to Production of Cement
[g/tonne of cement]

	Cement plant		**Quarry water**		**Storm water**		**Total**
	wght. avg.	range	wght. avg.	range	wght. avg.	range	wght. avg.
Suspended Solids	**69.05**	10.94-108.49	**53.05**	8.50-203.65	**0.45**	6.24-45.72	**122.54**
Aluminum	**0.28**	0.02-0.61	**0.17**	0.00-0.29			**0.45**
Phenolics	**0.00**	0.00-0.01	**0.00**	0.00-0.01	**0.00**	0.00	**0.01**
Oil & Grease	**2.48**	0.94-5.31	**1.45**	0.14-6.84	**0.00**	0.00-0.29	**3.94**
Nitrate, Nitrite	**0.82**	0.16-2.48	**2.24**	0.14-6.21	**0.01**	0.08-0.55	**3.06**
DOC	**4.74**	0.17-8.39	**2.47**	0.05-9.32			**7.21**
Chlorides	**79.72**	21.39-197.78	**297.17**	8.82-676.57	**0.65**	1.33-48.07	**377.53**
Sulphates	**147.50**	24.93-486.40	**173.00**	33.73-575.77	**0.66**	2.00-46.54	**321.16**
Sulphides	**0.01**	0.00-0.05	**0.03**	0.00-0.19			**0.04**
Ammonia, -um			**0.49**	0.05-1.03			**0.49**
Phosphorus			**0.00**	0.00-0.01			**0.00**
Zinc	**0.01**	0.00-0.06	**0.01**	0.00-0.10			**0.02**

Note: assumes 97% industry utilization (2004)

Table 6.2
Liquid Effluent due to Production of Cement
[mg/L of effluent]

	Cement plant		Quarry water		Stormwater	
	wght. avg.	range	wght. avg.	range	wght. avg.	range
Suspended Solids	37.53	10.36-150.93	50.97	24.65-182.55	0.88	.329-2.49
Aluminum	0.15	0.05-0.29	0.17	0.00-1.39	0.00	
Phenolics	0.00	0.00-0.01	0.00	0.00-0.03	0.00	0.00-0.01
Oil & Grease	1.35	1.19-2.41	1.40	0.74-2.55	0.01	0.00-1.49
Nitrate, Nitrite	0.45	0.00-0.56	2.15	0.13-6.77	0.01	0.42-5.26
DOC	2.58	0.45-4.99	2.37	0.13-4.67	0.00	
Chlorides	43.33	14.43-134.55	285.55	8.63-3284.12	1.27	1.2-2.62
Sulphates	80.17	20.07-584.24	166.24	40.59-331.70	1.28	0.19-2.39
Sulphides	0.00	0.01-0.02	0.03	0.00-0.08	0.00	
Ammonia, -um	0.00		0.47	0.17-3.11	0.00	
Phosphorus	0.00		0.00	0.00-0.04	0.00	
Zinc	0.00	0.00-0.02	0.01	0.00-0.02	0.00	
pH	8.26	8.25-8.41	8.15	7.79-8.88	8.84	8.13-10.5

Table 7.3
Cement Kiln Dust (CKD) Discarded as Solid Waste

City	CKD %	Total CKD kg/t of cement	Waste CKD kg/t of cement
Vancouver	1.35	19.989	2.99
Calgary	1.80	26.593	3.99
Winnipeg	1.80	26.593	3.99
Toronto	1.75	25.829	3.87
Montreal	3.74	46.928	7.04
Halifax	3.93	58.181	8.73

Note: personal correspondence G. Venta, CAC. December, 2005

3 Part II: Concrete Products

The revised cement estimates were cascaded through to develop corresponding life cycle inventory estimates for the structural concrete products incorporated in the Athena software. We assumed there were no changes in the inventory data for coarse and fine aggregates and supplementary cementing materials (SCM), and we assumed the same requirements for reinforcing steel components as in the original study.

The 1998 addendum added inventory data for 60 MPa concrete, using a mix design provided by CPCA. These data are repeated here for completeness.

As in the preceding section of this repot, the revised tables follow the explanatory notes.

3.1 Original Section 9

60 MPa concrete should be added to the list of the concrete products given in the introduction of this section. This update has dropped 15 Mpa ready mixed concrete as a product for study. After discussion with CAC it was determined that 15 MPA concrete is no longer specified by the industry (generally ready mixed concrete products all have a cement content of 200 kg or higher). The 15 MPa ready mixed concrete product will also be removed from the ATHENA EIE software.

3.2 Original Section 10

Revised Table 10.1 now includes the raw materials requirements for 60 MPa concrete as provided by CPCA. The 60 MPa (and higher strength) concrete often includes silica fume, a high performance by-product of the smelting process used to produce silicon metal and ferrosilicon alloys, as a supplementary cementing material.

Silica fume is an industrial by-product and, as in the case of fly ash, we have not attributed or allocated energy to its production. And since it is an extremely fine product, there is no need for further grinding/processing to make it suitable for use as a SCM.

Three North American producers of silica fume (information provided by Ming Zhang of NRCan and Nick Fagan of SKW, 2/19/99), one in Canada (Quebec) and two in the US (Ohio, West Virginia) have about an equal share of the business across the continent. The actual intercity mileage estimates between the points of origin, all in the eastern part of the continent, and the six cities under consideration in the study were used for the weighted average transportation calculations. We assumed that all the silica fume is transported by truck, 50% in bags with 100% backhaul and the other 50% in bulk, with no backhaul. This means that the actual transportation distances were multiplied by 1.5.

CAC indicated that SCM usage had increased in the formulations of 20 and 30 MPa ready mixed concrete. In the original and 1998 addendum reports, SCM usage for 20 and 30 MPa ready mixed products was about 10% of the total cementacious material content of the concrete. SCM usage has now risen to approximately 15% of the total cementacious material content with a corresponding decline in cement usage. CAC also confirmed that there was no change (increase) in the use of SCM for the other strengths of ready mixed and the formulation of the other structural concrete products therefore remains unchanged.

3.3 Original Section 11

Following are the transportation energy estimates for silica fume, based on the assumptions described above (as provided in the 1998 addendum):

City	Diesel – Road GJ/t
Vancouver	7.92582
Calgary	6.23512
Winnipeg	3.98557
Toronto	1.20454
Montreal	1.41978
Halifax	3.11426

Other raw material extraction, processing and transportation energy estimates remain the same as in the original study.

Tables 11.1 through 11.14 give updated energy use by process stage and/or fuel type for the six types of concrete products from the earlier study, with Tables 11.3A and 11.6A inserted to cover 60 MPa ready mixed concrete.

3.4 Original Section 12

There is no change to this section.

3.5 Original Section 13

Tables 13.1 and 13.2 remain unchanged. Atmospheric emissions due to the transportation of silica fume used in 60 MPa concrete are given in Table 13.2A.

The updated atmospheric emissions for the eight concrete products under consideration, are given in Tables 13.2-13.10 (note that a table has been added to the original series to cover 60MPa ready mixed).

3.6 Original Section 14

Tables 14.1-14.3 remain unchanged, while Tables 14.4-14.6 provide the updated effluent data. For the reasons discussed in Section 7, Part I, Tables 14.4 and 14.6 show lower emissions to water and pollutant flows in 1997 than in 1991.

3.7 Original Section 15

Data for a 60 MPa concrete was added to Tables 15.1-15.3.

3.8 Original Section 16

This section of the original report, which summarized the results by consolidating key tables from earlier sections, need not be repeated here.

3.9 Revised Tables

Table 10.1
Raw material requirements by concrete product
(kg/m^3)

RAW MATERIAL	PRODUCT							
	15 MPa Ready Mixed	20 MPa Ready Mixed	30 MPa Ready Mixed	60 MPa Ready Mixed	Block	Double T Beam	Hollow Deck	Cement Mortar
Cement	-	204	297	352	189	505	505	307
Fly ash	-	36	53	-	-	-	-	-
Blast furnace slag								
Silica fume	-	-	-	33	-	-	-	-
Coarse aggregate	-	1009	1092	1088	510	750	750	-
Fine aggregate	-	925	722	748	1191	744	744	785
Water	-	160	160	165	53	202	202	185
Total	-	2334	2324	2386	1943	2201	2201	1277

Sources: 1. 20 MPa and 30 MPa ready mixed concrete - CAC, private correspondence from G. Venta, Director, December 1, 2005.
2. 60 MPa ready mixed concrete - CPCA, correspondence from A.Cornelissen, Manager-Building Science, September, 1998.
3. Block - J.L Schmidt, H. Bennett and W.H. Lewis, *Construction Principles, Materials and Methods* (ASLIP, Chicago, Ill., 1972).
4. Double T and hollow deck - same source as for ready mixed.
5. Cement Mortar - F.M. Lea, *The Chemistry of Cement and Concrete* (Chemical Publishing Company, Inc., New York, 1971), p. 531.

Table 11.2
Energy Use in 20 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing			
			Cement	Processing	Sub-total	
West Coast						
Vancouver	0.09519	0.09029	0.84340	0.24274	1.08614	1.27162
Prairie						
Calgary	0.09309	0.07100	1.00277	0.24274	1.24551	1.40959
Winnipeg	0.09309	0.06081	1.19007	0.24274	1.43280	1.58669
Central						
Toronto	0.09730	0.07644	0.94989	0.24274	1.19262	1.36636
East						
Montreal	0.09309	0.06948	1.10921	0.24274	1.35195	1.51452
Halifax	0.09309	0.06081	1.12344	0.24274	1.36618	1.52007

Table 11.3
Energy Use in 30 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Processing	Sub-total	Total
West Coast						
Vancouver	0.08723	0.08038	1.22996	0.24170	1.47165	1.63927
Prairie						
Calgary	0.08416	0.06377	1.46237	0.24170	1.70407	1.85200
Winnipeg	0.08416	0.05499	1.73551	0.24170	1.97721	2.11636
Central						
Toronto	0.09031	0.06845	1.38525	0.24170	1.62695	1.78570
East						
Montreal	0.08416	0.06246	1.61760	0.24170	1.85930	2.00592
Halifax	0.08416	0.05499	1.63836	0.24170	1.88005	2.01920

Table 11.3A
Energy Use in 60 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Processing	Sub-total	Total
West Coast						
Vancouver	0.08556	0.29786	1.45528	0.24814	1.70342	2.08684
Prairie						
Calgary	0.08556	0.24544	1.73027	0.24814	1.97841	2.30942
Winnipeg	0.08556	0.17571	2.05345	0.24814	2.30159	2.56286
Central						
Toronto	0.08556	0.08950	1.63902	0.24814	1.88716	2.06222
East						
Montreal	0.08556	0.09617	1.91394	0.24814	2.16208	2.34381
Halifax	0.08556	0.14870	1.93849	0.24814	2.18664	2.42089

Table 11.5
Energy Use in 20 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form: Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	Total
West Coast										
Vancouver	0.29092	0.02479	0.02371	0.19477	0.44657	0.04085	0.03319	0.03600	0.18083	1.27162
Prairie										
Calgary	0.36108	0.04020	0.00000	0.18022	0.53276	0.04085	0.06890	0.00000	0.18559	1.40959
Winnipeg	0.27629	0.30209	0.00000	0.18022	0.53276	0.04085	0.06890	0.00000	0.18559	1.58669
Central										
Toronto	0.33402	0.00093	0.00613	0.18329	0.33121	0.08424	0.20398	0.03694	0.18560	1.36636
East										
Montreal	0.29931	0.00040	0.01241	0.12669	0.34919	0.07419	0.21985	0.25541	0.17707	1.51452
Halifax	0.31606	0.00000	0.00161	0.12669	0.34919	0.07419	0.21985	0.25541	0.17707	1.52007

Table 11.6
Energy Use in 30 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.29664	0.02140	0.03045	0.26514	0.65125	0.04067	0.04840	0.05249	0.23283	1.63927
Prairie										
Calgary	0.39161	0.05862	0.00000	0.24392	0.77695	0.04067	0.10048	0.00000	0.23976	1.85200
Winnipeg	0.27404	0.44055	0.00000	0.24392	0.77695	0.04067	0.10048	0.00000	0.23976	2.11636
Central										
Toronto	0.34890	0.00136	0.00895	0.24840	0.48301	0.10396	0.29747	0.05387	0.23978	1.78570
East										
Montreal	0.30887	0.00058	0.01164	0.16586	0.50923	0.08931	0.32062	0.37248	0.22733	2.00592
Halifax	0.33204	0.00000	0.00234	0.16586	0.50923	0.08931	0.32062	0.37248	0.22733	2.01920

Table 11.6A
Energy Use in 60 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.55464	0.00015	0.02899	0.30735	0.77055	0.04176	0.05727	0.06211	0.26402	2.08684
Prairie										
Calgary	0.60205	0.06936	0.00000	0.28224	0.91928	0.04176	0.11888	0.00000	0.27586	2.30942
Winnipeg	0.40359	0.52126	0.00000	0.28224	0.91928	0.04176	0.11888	0.00000	0.27586	2.56286
Central										
Toronto	0.39003	0.00161	0.01058	0.28755	0.57149	0.11664	0.35197	0.06374	0.26861	2.06222
East										
Montreal	0.36743	0.00069	0.00277	0.18988	0.60252	0.09930	0.37935	0.44071	0.26115	2.34381
Halifax	0.44521	0.00000	0.00277	0.18988	0.60252	0.09930	0.37935	0.44071	0.26115	2.42089

Table 11.7
Energy Use in Concrete Block Production by Process Stage
[GJ/block]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing			
			Cement	Processing	Sub-total	
West Coast						
Vancouver	0.00087	0.00052	0.00751	0.01241	0.01992	0.02131
Prairie						
Calgary	0.00087	0.00052	0.00893	0.01241	0.02134	0.02273
Winnipeg	0.00087	0.00052	0.01060	0.01241	0.02301	0.02439
Central						
Toronto	0.00087	0.00052	0.00846	0.01241	0.02087	0.02225
East						
Montreal	0.00087	0.00052	0.00988	0.01241	0.02229	0.02367
Halifax	0.00087	0.00052	0.01001	0.01241	0.02241	0.02380

Table 11.8
Energy Use Concrete Block Production by Energy Form
[GJ/block]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.00363	0.00000	0.00015	0.01021	0.00398	0.00000	0.00030	0.00032	0.00272	0.02131
Prairie										
Calgary	0.00414	0.00036	0.00000	0.01008	0.00475	0.00000	0.00061	0.00000	0.00278	0.02273
Winnipeg	0.00348	0.00269	0.00000	0.01008	0.00475	0.00000	0.00061	0.00000	0.00278	0.02439
Central										
Toronto	0.00386	0.00001	0.00005	0.01011	0.00295	0.00039	0.00182	0.00033	0.00275	0.02225
East										
Montreal	0.00370	0.00000	0.00001	0.00960	0.00311	0.00030	0.00196	0.00228	0.00271	0.02367
Halifax	0.00383	0.00000	0.00001	0.00960	0.00311	0.00030	0.00196	0.00228	0.00271	0.02380

Table 11.9
Energy Use in Cement Mortar Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing			
			Cement	Processing	Sub-total	
West Coast						
Vancouver	0.04663	0.02779	1.26923	0.00395	1.27318	1.34760
Prairie						
Calgary	0.04663	0.02779	1.50907	0.00395	1.51302	1.58744
Winnipeg	0.04663	0.02779	1.79093	0.00395	1.79488	1.86930
Central						
Toronto	0.04663	0.02779	1.42949	0.00395	1.43344	1.50785
East						
Montreal	0.04663	0.02779	1.66926	0.00395	1.67321	1.74763
Halifax	0.04663	0.02779	1.69067	0.00395	1.69462	1.76904

Table 11.10
Energy Use Cement Mortar Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.09861	0.00014	0.02528	0.23164	0.67204	0.00000	0.04995	0.05417	0.21578	1.34760
Prairie										
Calgary	0.18566	0.06049	0.00000	0.20974	0.80176	0.00000	0.10368	0.00000	0.22610	1.58744
Winnipeg	0.07340	0.45462	0.00000	0.20974	0.80176	0.00000	0.10368	0.00000	0.22610	1.86930
Central										
Toronto	0.13676	0.00141	0.00923	0.21437	0.49843	0.06531	0.30697	0.05559	0.21979	1.50786
East										
Montreal	0.11123	0.00060	0.00242	0.12918	0.52549	0.05019	0.33085	0.38437	0.21328	1.74763
Halifax	0.13325	0.00000	0.00242	0.12918	0.52549	0.05019	0.33085	0.38437	0.21328	1.76904

Table 11.11
Energy Use in Double T Beam Production by Process Stage
[GJ/metre of 10' wide beam]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.02154	0.01792	0.61991	0.14482	0.76473	0.80420
Prairie						
Calgary	0.02154	0.01792	0.73705	0.14482	0.88187	0.92134
Winnipeg	0.02154	0.01792	0.87471	0.14482	1.01954	1.05900
Central						
Toronto	0.02154	0.01792	0.69818	0.14482	0.84300	0.88247
East						
Montreal	0.02154	0.01792	0.81529	0.14482	0.96011	0.99957
Halifax	0.02154	0.01792	0.82575	0.14482	0.97057	1.01003

Table 11.12
Energy Use in Hollow Deck Production by Process Stage
[GJ/metre of 4' wide by 8" deep slab]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.01233	0.01033	0.35493	0.08292	0.43785	0.46051
Prairie						
Calgary	0.01233	0.01033	0.42200	0.08292	0.50492	0.52758
Winnipeg	0.01233	0.01033	0.50082	0.08292	0.58374	0.60640
Central						
Toronto	0.01233	0.01033	0.39974	0.08292	0.48266	0.50533
East						
Montreal	0.01233	0.01033	0.46679	0.08292	0.54971	0.57238
Halifax	0.01233	0.01033	0.47278	0.08292	0.55570	0.57837

Table 11.13
Energy Use in Double T Beam Production by Energy Form
[GJ/metre of 10' wide beam]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.07505	0.00007	0.01235	0.21156	0.32823	0.00000	0.02439	0.02646	0.12609	0.80420
Prairie										
Calgary	0.11757	0.02954	0.00000	0.20086	0.39159	0.00000	0.05064	0.00000	0.13113	0.92134
Winnipeg	0.06274	0.22204	0.00000	0.20086	0.39159	0.00000	0.05064	0.00000	0.13113	1.05900
Central										
Toronto	0.09368	0.00069	0.00451	0.20312	0.24344	0.03190	0.14993	0.02715	0.12804	0.88247
East										
Montreal	0.08122	0.00029	0.00118	0.16152	0.25666	0.02451	0.16159	0.18773	0.12487	0.99957
Halifax	0.09197	0.00000	0.00118	0.16152	0.25666	0.02451	0.16159	0.18773	0.12487	1.01003

Table 11.14
Energy Use in Hollow Deck Production by Energy Form
[GJ/metre of 4' wide by 8" deep slab]

Region	Energy Form: Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	Total
West Coast										
Vancouver	0.04304	0.00004	0.00707	0.12113	0.18793	0.00000	0.01397	0.01515	0.07219	0.46052
Prairie										
Calgary	0.06738	0.01692	0.00000	0.11500	0.22420	0.00000	0.02899	0.00000	0.07508	0.52758
Winnipeg	0.03599	0.12713	0.00000	0.11500	0.22420	0.00000	0.02899	0.00000	0.07508	0.60640
Central										
Toronto	0.05371	0.00039	0.00258	0.11630	0.13938	0.01826	0.08584	0.01555	0.07331	0.50533
East										
Montreal	0.04657	0.00017	0.00068	0.09248	0.14695	0.01403	0.09252	0.10749	0.07149	0.57238
Halifax	0.05273	0.00000	0.00068	0.09248	0.14695	0.01403	0.09252	0.10749	0.07149	0.57837

Table 13.2A
Atmospheric Emissions due to Transportation of Silica Fume

City	CO2 [kg/tonne]	SO2 [g/tonne]	NOx [g/tonne]	VOC [g/tonne]	CH4 [g/tonne]	CO [g/tonne]
Vancouver	560.3558	0.8084	6.3961	0.6888	0.1720	3.5111
Calgary	440.8230	0.6360	5.0317	0.5418	0.1353	2.7622
Winnipeg	74.6856	4.0876	4.7926	4.0725	4.0073	4.4286
Toronto	85.1613	0.1229	0.9721	0.1047	0.0261	0.5336
Montreal	100.3782	0.1448	1.1458	0.1234	0.0308	0.6290
Halifax	220.1779	0.3177	2.5132	0.2706	0.0676	1.3796

Table 13.4
Atmospheric Emissions due to 20 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Prairie	Calgary	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Winnipeg	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Central	Toronto	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
East	Montreal	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Halifax	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Raw Material Transportation								
West Coast	Vancouver	6406.27	11.61	83.31	9.32	1.74	27.45	
Prairie	Calgary	5019.74	7.24	57.30	6.17	1.54	31.45	
	Winnipeg	4298.94	6.20	49.07	5.28	1.32	26.94	
Central	Toronto	5404.17	7.80	61.69	6.64	1.66	33.86	
East	Montreal	4947.97	10.85	49.52	8.99	1.71	26.08	
	Halifax	4298.94	6.20	49.07	5.28	1.32	26.94	
Concrete Processing								
West Coast	Vancouver	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Prairie	Calgary	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Winnipeg	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Central	Toronto	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
East	Montreal	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Halifax	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Cement Production								
West Coast	Vancouver	171286.83	21.42	1018.92	10.54	2.02	65.72	289.13
Prairie	Calgary	185957.06	27.29	1231.99	12.58	2.98	107.10	387.93
	Winnipeg	200107.68	47.71	1559.48	25.24	3.43	87.74	387.93
Central	Toronto	177012.23	32.13	505.38	9.05	2.20	82.77	257.32
East	Montreal	189586.38	41.99	686.10	5.92	1.80	76.89	369.87
	Halifax	190661.50	43.54	698.12	7.25	2.14	83.79	313.14
Processing Sub-total								
West Coast	Vancouver	186698.46	41.44	1142.52	23.39	5.27	132.10	409.13
Prairie	Calgary	201368.69	47.32	1355.60	25.43	6.23	173.49	507.93
	Winnipeg	215519.31	67.73	1683.08	38.09	6.68	154.13	507.93
Central	Toronto	192423.86	52.15	628.98	21.90	5.45	149.15	377.32
East	Montreal	204998.02	62.01	809.70	18.77	5.05	143.27	489.87
	Halifax	206073.14	63.56	821.72	20.10	5.39	150.17	433.14
TOTAL								
West Coast	Vancouver	196796.55	58.38	1267.98	37.25	8.14	182.69	505.83
Prairie	Calgary	210080.25	59.88	1455.04	36.14	8.90	228.08	604.63
	Winnipeg	223510.07	79.26	1774.29	47.91	9.14	204.20	604.63
Central	Toronto	201519.85	65.28	732.81	33.08	8.25	206.15	474.02
East	Montreal	213637.81	78.18	901.36	32.30	7.89	192.48	586.57
	Halifax	214063.89	75.09	912.93	29.92	7.84	200.24	529.84

Table 13.5
Atmospheric Emissions due to 30 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Prairie	Calgary	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Winnipeg	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Central	Toronto	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
East	Montreal	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Halifax	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Raw Material Transportation								
West Coast	Vancouver	5702.30	10.27	73.86	8.25	1.56	24.81	
Prairie	Calgary	4508.34	6.50	51.46	5.54	1.38	28.25	
	Winnipeg	3887.65	5.61	44.38	4.78	1.19	24.36	
Central	Toronto	4839.38	6.98	55.24	5.95	1.49	30.32	
East	Montreal	4446.54	9.61	44.76	7.97	1.53	23.62	
	Halifax	3887.65	5.61	44.38	4.78	1.19	24.36	
Concrete Processing								
West Coast	Vancouver	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Prairie	Calgary	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Winnipeg	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Central	Toronto	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
East	Montreal	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Halifax	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Cement Production								
West Coast	Vancouver	250644.49	31.34	1490.99	15.43	2.95	96.17	423.08
Prairie	Calgary	272111.48	39.94	1802.78	18.40	4.36	156.73	567.66
	Winnipeg	292818.11	69.81	2281.99	36.93	5.02	128.39	567.66
Central	Toronto	259022.48	47.02	739.52	13.24	3.23	121.11	376.53
East	Montreal	277422.28	61.44	1003.97	8.66	2.64	112.51	541.24
	Halifax	278995.50	63.71	1021.56	10.61	3.13	122.61	458.22
Processing Sub-total								
West Coast	Vancouver	265990.09	51.28	1614.06	28.22	6.19	162.27	543.08
Prairie	Calgary	287457.08	59.87	1925.86	31.20	7.60	222.83	687.66
	Winnipeg	308163.72	89.75	2405.06	49.73	8.26	194.49	687.66
Central	Toronto	274368.09	66.95	862.60	26.03	6.46	187.21	496.53
East	Montreal	292767.88	81.38	1127.04	21.46	5.87	178.61	661.24
	Halifax	294341.11	83.65	1144.63	23.40	6.36	188.71	578.22
TOTAL								
West Coast	Vancouver	275155.13	66.55	1727.45	40.73	8.81	208.77	633.78
Prairie	Calgary	295428.17	71.37	2016.84	41.00	10.04	272.77	778.36
	Winnipeg	315514.11	100.35	2488.96	58.76	10.52	240.55	778.36
Central	Toronto	282670.21	78.93	957.36	36.24	9.01	239.23	587.23
East	Montreal	300677.17	95.98	1211.33	33.68	8.46	223.92	751.94
	Halifax	301691.51	94.25	1228.53	32.44	8.62	234.76	668.92

Table 13.5A
Atmospheric Emissions due to 60 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Prairie	Calgary	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
	Winnipeg	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Central	Toronto	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
East	Montreal	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
	Halifax	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Raw Material Transportation								
West Coast	Vancouver	21058.46	30.38	240.37	25.88	6.46	131.95	
Prairie	Calgary	17352.94	25.04	198.07	21.33	5.33	108.73	
	Winnipeg	12422.60	17.92	141.80	15.27	3.81	77.84	
Central	Toronto	6327.43	9.13	72.22	7.78	1.94	39.65	
East	Montreal	6799.15	9.81	77.61	8.36	2.09	42.60	
	Halifax	10512.94	15.17	120.00	12.92	3.23	65.87	
Concrete Processing								
West Coast	Vancouver	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Prairie	Calgary	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
	Winnipeg	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Central	Toronto	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
East	Montreal	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
	Halifax	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Cement Production								
West Coast	Vancouver	250644.49	31.34	1490.99	15.43	2.95	96.17	423.08
Prairie	Calgary	272111.48	39.94	1802.78	18.40	4.36	156.73	567.66
	Winnipeg	292818.11	69.81	2281.99	36.93	5.02	128.39	567.66
Central	Toronto	259022.48	47.02	739.52	13.24	3.23	121.11	376.53
East	Montreal	277422.28	61.44	1003.97	8.66	2.64	112.51	541.24
	Halifax	278995.50	63.71	1021.56	10.61	3.13	122.61	458.22
Processing Sub-total								
West Coast	Vancouver	266399.48	51.81	1617.35	28.56	6.27	164.03	543.08
Prairie	Calgary	287866.47	60.41	1929.14	31.54	7.68	224.59	687.66
	Winnipeg	308573.11	90.28	2408.35	50.07	8.35	196.26	687.66
Central	Toronto	274777.48	67.49	865.88	26.38	6.55	188.98	496.53
East	Montreal	293177.27	81.91	1130.33	21.80	5.96	180.37	661.24
	Halifax	294750.50	84.18	1147.92	23.74	6.45	190.47	578.22
TOTAL								
West Coast	Vancouver	290962.68	87.25	1897.72	58.75	13.81	317.94	633.78
Prairie	Calgary	308724.16	90.50	2167.22	57.18	14.09	355.28	778.36
	Winnipeg	324500.45	113.26	2590.15	69.65	13.23	296.06	778.36
Central	Toronto	284609.65	81.67	978.11	38.46	9.57	250.58	587.23
East	Montreal	303481.17	96.78	1247.94	34.46	9.12	244.94	751.94
	Halifax	308768.19	104.40	1307.92	40.97	10.75	278.31	668.92

Table 13.6
Atmospheric Emissions due to Concrete Block Production
by Process Stage and Region
[grams/block]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Prairie	Calgary	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Winnipeg	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Central	Toronto	31.22	0.05	0.36	0.04	0.01	0.20	0.82
East	Montreal	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Halifax	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Raw Material Transportation								
West Coast	Vancouver	36.84	0.05	0.42	0.05	0.01	0.23	
Prairie	Calgary	36.84	0.05	0.42	0.05	0.01	0.23	
	Winnipeg	36.84	0.05	0.42	0.05	0.01	0.23	
Central	Toronto	36.84	0.05	0.42	0.05	0.01	0.23	
East	Montreal	36.84	0.05	0.42	0.05	0.01	0.23	
	Halifax	36.84	0.05	0.42	0.05	0.01	0.23	
Concrete Processing								
West Coast	Vancouver	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Prairie	Calgary	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Winnipeg	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Central	Toronto	606.94	0.24	2.44	0.22	0.06	1.18	1.15
East	Montreal	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Halifax	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Cement Production								
West Coast	Vancouver	1427.89	0.18	8.49	0.09	0.02	0.55	2.41
Prairie	Calgary	1550.18	0.23	10.27	0.10	0.02	0.89	3.23
	Winnipeg	1668.15	0.40	13.00	0.21	0.03	0.73	3.23
Central	Toronto	1475.62	0.27	4.21	0.08	0.02	0.69	2.15
East	Montreal	1580.44	0.35	5.72	0.05	0.02	0.64	3.08
	Halifax	1589.40	0.36	5.82	0.06	0.02	0.70	2.61
Processing Sub-total								
West Coast	Vancouver	2034.83	0.42	10.93	0.30	0.08	1.73	3.56
Prairie	Calgary	2157.13	0.47	12.71	0.32	0.09	2.08	4.39
	Winnipeg	2275.09	0.64	15.44	0.43	0.09	1.92	4.39
Central	Toronto	2082.56	0.51	6.65	0.29	0.08	1.87	3.30
East	Montreal	2187.38	0.59	8.16	0.27	0.08	1.82	4.24
	Halifax	2196.34	0.61	8.26	0.28	0.08	1.88	3.76
TOTAL								
West Coast	Vancouver	2102.90	0.52	11.71	0.39	0.10	2.16	4.38
Prairie	Calgary	2225.19	0.57	13.48	0.41	0.11	2.50	5.21
	Winnipeg	2343.16	0.74	16.21	0.51	0.11	2.34	5.21
Central	Toronto	2150.63	0.61	7.43	0.38	0.10	2.30	4.12
East	Montreal	2255.45	0.69	8.93	0.35	0.10	2.25	5.05
	Halifax	2264.41	0.70	9.03	0.36	0.10	2.31	4.58

Table 13.7
Atmospheric Emissions due to Cement Mortar Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Prairie	Calgary	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Winnipeg	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Central	Toronto	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
East	Montreal	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Halifax	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Raw Material Transportation								
West Coast	Vancouver	1964.68	2.83	22.43	2.41	0.60	12.31	
Prairie	Calgary	1964.68	2.83	22.43	2.41	0.60	12.31	
	Winnipeg	1964.68	2.83	22.43	2.41	0.60	12.31	
Central	Toronto	1964.68	2.83	22.43	2.41	0.60	12.31	
East	Montreal	1964.68	2.83	22.43	2.41	0.60	12.31	
	Halifax	1964.68	2.83	22.43	2.41	0.60	12.31	
Concrete Processing								
West Coast	Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Prairie	Calgary	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Winnipeg	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Central	Toronto	0.00	0.00	0.00	0.00	0.00	0.00	120.00
East	Montreal	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Halifax	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Cement Production								
West Coast	Vancouver	241215.85	30.17	1434.90	14.85	2.84	92.55	407.16
Prairie	Calgary	261875.31	38.44	1734.96	17.71	4.20	150.83	546.31
	Winnipeg	281803.01	67.19	2196.14	35.54	4.83	123.56	546.31
Central	Toronto	249278.69	45.25	711.70	12.74	3.10	116.56	362.37
East	Montreal	266986.33	59.13	966.20	8.34	2.54	108.28	520.88
	Halifax	268500.38	61.32	983.13	10.21	3.01	117.99	440.99
Processing Sub-total								
West Coast	Vancouver	241215.85	30.17	1434.90	14.85	2.84	92.55	527.16
Prairie	Calgary	261875.31	38.44	1734.96	17.71	4.20	150.83	666.31
	Winnipeg	281803.01	67.19	2196.14	35.54	4.83	123.56	666.31
Central	Toronto	249278.69	45.25	711.70	12.74	3.10	116.56	482.37
East	Montreal	266986.33	59.13	966.20	8.34	2.54	108.28	640.88
	Halifax	268500.38	61.32	983.13	10.21	3.01	117.99	560.99
TOTAL								
West Coast	Vancouver	244679.02	35.16	1474.43	19.10	3.90	114.25	566.41
Prairie	Calgary	265338.48	43.43	1774.49	21.97	5.26	172.53	705.56
	Winnipeg	285266.18	72.18	2235.67	39.80	5.90	145.26	705.56
Central	Toronto	252741.86	50.24	751.23	17.00	4.17	138.26	521.62
East	Montreal	270449.50	64.13	1005.73	12.59	3.60	129.98	680.13
	Halifax	271963.54	66.31	1022.66	14.46	4.07	139.69	600.24

Table 13.8
Atmospheric Emissions due to Double T Beam Production
by Process Stage and Region
[grams/metre of 10' wide beam]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Prairie	Calgary	846.77	1.22	9.67	1.04	0.26	5.31	22.18
	Winnipeg	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Central	Toronto	846.77	1.22	9.67	1.04	0.26	5.31	22.18
East	Montreal	846.77	1.22	9.67	1.04	0.26	5.31	22.18
	Halifax	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Raw Material Transportation								
West Coast	Vancouver	1267.28	1.83	14.47	1.56	0.39	7.94	
Prairie	Calgary	1267.28	1.83	14.47	1.56	0.39	7.94	
	Winnipeg	1267.28	1.83	14.47	1.56	0.39	7.94	
Central	Toronto	1267.28	1.83	14.47	1.56	0.39	7.94	
East	Montreal	1267.28	1.83	14.47	1.56	0.39	7.94	
	Halifax	1267.28	1.83	14.47	1.56	0.39	7.94	
Concrete Processing								
West Coast	Vancouver	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Prairie	Calgary	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
	Winnipeg	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Central	Toronto	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
East	Montreal	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
	Halifax	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Cement Production								
West Coast	Vancouver	117812.79	14.73	700.82	7.25	1.39	45.20	198.86
Prairie	Calgary	127903.12	18.77	847.38	8.65	2.05	73.67	266.82
	Winnipeg	137636.06	32.81	1072.62	17.36	2.36	60.35	266.82
Central	Toronto	121750.78	22.10	347.60	6.22	1.52	56.93	176.98
East	Montreal	130399.41	28.88	471.91	4.07	1.24	52.88	254.40
	Halifax	131138.89	29.95	480.17	4.99	1.47	57.63	215.38
Processing Sub-total								
West Coast	Vancouver	124183.01	16.89	723.51	9.19	1.97	55.94	234.49
Prairie	Calgary	134273.34	20.93	870.06	10.59	2.63	84.41	302.45
	Winnipeg	144006.27	34.97	1095.31	19.30	2.94	71.09	302.45
Central	Toronto	128120.99	24.25	370.29	8.16	2.10	67.67	212.61
East	Montreal	136769.62	31.03	494.59	6.01	1.82	63.62	290.03
	Halifax	137509.10	32.10	502.86	6.92	2.05	68.37	251.01
TOTAL								
West Coast	Vancouver	126297.06	19.94	747.64	11.78	2.62	69.19	256.67
Prairie	Calgary	136387.39	23.98	894.19	13.18	3.28	97.65	324.63
	Winnipeg	146120.32	38.02	1119.44	21.89	3.59	84.34	324.63
Central	Toronto	130235.04	27.30	394.42	10.76	2.75	80.91	234.79
East	Montreal	138883.67	34.08	518.72	8.61	2.47	76.87	312.21
	Halifax	139623.15	35.15	526.99	9.52	2.70	81.62	273.19

Table 13.9
Atmospheric Emissions due to Hollow Deck Production by Process Stage and Region
[grams/metre of 4' wide by 8" deep slab]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Prairie	Calgary	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Winnipeg	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Central	Toronto	484.82	0.70	5.53	0.60	0.15	3.04	12.70
East	Montreal	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Halifax	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Raw Material Transportation								
West Coast	Vancouver	730.49	1.05	8.34	0.90	0.22	4.58	
Prairie	Calgary	730.49	1.05	8.34	0.90	0.22	4.58	
	Winnipeg	730.49	1.05	8.34	0.90	0.22	4.58	
Central	Toronto	730.49	1.05	8.34	0.90	0.22	4.58	
East	Montreal	730.49	1.05	8.34	0.90	0.22	4.58	
	Halifax	730.49	1.05	8.34	0.90	0.22	4.58	
Concrete Processing								
West Coast	Vancouver	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Prairie	Calgary	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Winnipeg	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Central	Toronto	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
East	Montreal	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Halifax	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Cement Production								
West Coast	Vancouver	67454.01	8.44	401.26	4.15	0.79	25.88	113.86
Prairie	Calgary	73231.25	10.75	485.17	4.95	1.17	42.18	152.77
	Winnipeg	78803.87	18.79	614.13	9.94	1.35	34.55	152.77
Central	Toronto	69708.72	12.65	199.02	3.56	0.87	32.59	101.33
East	Montreal	74660.51	16.54	270.19	2.33	0.71	30.28	145.66
	Halifax	75083.90	17.15	274.92	2.85	0.84	33.00	123.32
Processing Sub-total								
West Coast	Vancouver	71101.29	9.67	414.25	5.26	1.13	32.03	134.26
Prairie	Calgary	76878.54	11.98	498.16	6.06	1.51	48.33	173.17
	Winnipeg	82451.15	20.02	627.12	11.05	1.68	40.70	173.17
Central	Toronto	73356.00	13.89	212.01	4.67	1.20	38.74	121.73
East	Montreal	78307.79	17.77	283.18	3.44	1.04	36.43	166.06
	Halifax	78731.18	18.38	287.91	3.96	1.17	39.15	143.72
TOTAL								
West Coast	Vancouver	72316.60	11.42	428.12	6.75	1.50	39.64	146.96
Prairie	Calgary	78093.85	13.73	512.03	7.55	1.88	55.94	185.87
	Winnipeg	83666.46	21.77	640.99	12.54	2.06	48.32	185.87
Central	Toronto	74571.31	15.64	225.88	6.16	1.57	46.36	134.43
East	Montreal	79523.10	19.52	297.05	4.93	1.42	44.04	178.76
	Halifax	79946.49	20.13	301.78	5.46	1.55	46.76	156.42

Table 14.4
Estimated Effluent Flows by Concrete Product
(liters/m3 of concrete)

	20MPa Ready Mixed	30MPa Ready Mixed	60MPa Ready Mixed	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Cement plant water	436.69	639.01	705.12	378.60	614.97	1011.60	1011.60
Quarry water	221.80	324.56	358.13	192.29	312.35	513.80	513.80
Stormwater	0.39	0.58	0.64	0.34	0.56	0.91	0.91
Aggregate quarry water	454.26	426.07	431.24	399.53	184.38	350.91	350.91
Concrete process water	50.00	50.00	50.00	12.50	25.00	12.50	12.50
Totals	1163.14	1440.22	1545.13	983.26	1137.26	1889.72	1889.72
Total liters per block or metre				9.45		561.09	321.25

Table 14.5
Weighted Average Liquid Effluents by Product
(mg/L of Effluent)

	20MPa Ready Mixed	30MPa Ready Mixed	60MPa Ready Mixed	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Suspended Solids	47.1302	52.8521	53.8484	45.6229	60.9127	59.1939	59.1939
Aluminum	0.1877	0.2218	0.2281	0.1927	0.2703	0.2676	0.2676
Phenolics	0.0029	0.0034	0.0035	0.0029	0.0041	0.0041	0.0041
Oil & Grease	1.5258	1.5218	1.5157	1.3354	1.5098	1.4054	1.4054
Nitrate, Nitrite	0.6751	0.7978	0.8206	0.6927	0.9724	0.9626	0.9626
DOC	1.4326	1.6931	1.7414	1.4701	2.0634	2.0427	2.0427
Chlorides	228.2461	269.7378	277.4332	234.4127	328.7447	325.4412	325.4412
Sulphates	78.0593	92.2493	94.8811	80.0686	112.4295	111.2997	111.2997
Sulphides	0.0071	0.0084	0.0087	0.0073	0.0103	0.0102	0.0102
Ammonia, -um	0.2309	0.2728	0.2806	0.2372	0.3325	0.3292	0.3292
Phosphorus	0.0015	0.0018	0.0018	0.0015	0.0021	0.0021	0.0021
pH	8.07	8.11	8.11	8.07	8.16	8.15	8.15

Table 14.6
Weighted Average Liquid Effluents by Product
(g/unit of product)

	20MPa Ready Mixed per m3	30MPa Ready Mixed per m3	60MPa Ready Mixed per m3	Concrete Block per block	Cement Mortar per m3	Double T Beam per m	Hollow Deck per m
Suspended Solids	54.8191	76.1185	83.2025	0.4313	69.2734	33.2131	19.0162
Aluminum	0.2183	0.3194	0.3524	0.0018	0.3074	0.1501	0.0860
Phenolics	0.0033	0.0049	0.0054	0.0000	0.0047	0.0023	0.0013
Oil & Grease	1.7747	2.1917	2.3419	0.0126	1.7170	0.7886	0.4515
Nitrate, Nitrite	0.7853	1.1491	1.2679	0.0065	1.1058	0.5401	0.3092
DOC	1.6663	2.4384	2.6906	0.0139	2.3466	1.1461	0.6562
Chlorides	265.4826	388.4814	428.6691	2.2162	373.8677	182.6016	104.5490
Sulphates	90.7941	132.8592	146.6033	0.7570	127.8614	62.4491	35.7554
Sulphides	0.0083	0.0122	0.0134	0.0001	0.0117	0.0057	0.0033
Ammonia, -um	0.2685	0.3929	0.4336	0.0022	0.3781	0.1847	0.1057
Phosphorus	0.0017	0.0025	0.0028	0.0000	0.0024	0.0012	0.0007

Table 15.1
Solid Wastes due to the Production of Cement
(per unit of concrete product by city)

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
20 MPa Ready Miixed [kg/m3]	0.61	0.81	0.81	0.79	1.44	1.78
30 MPa Ready Miixed [kg/m3]	0.89	1.19	1.19	1.15	2.09	2.59
60 MPa Ready Miixed [kg/m3]	1.05	1.40	1.40	1.36	2.48	3.07
Concrete Block [kg/block]	0.01	0.01	0.01	0.01	0.01	0.02
Cement Mortar [kg/m3]	0.92	1.22	1.22	1.19	2.16	2.68
Double T Beam [kg/m, 10' width]	1.51	2.01	2.01	1.95	3.56	4.41
Hollow Deck [kg/m, 4'w, 8"t]	1.51	2.01	2.01	1.95	3.56	4.41

Table 15.2
Solid Wastes due to Concrete Products Manufacturing

Concrete Material	Solid Wastes
20 MPa Ready Mixed	48.46 [kg/m3]
30 MPa Ready Mixed	48.35 [kg/m3]
60 MPa Ready Mixed	49.01 [kg/m3]
Concrete Block	0.025 [kg/block]
Cement Mortar	2.59 [kg/m3]
Double T Beam	0.769 [kg/m, 10' width]
Hollow Deck	0.440 [kg/m, 4'w, 8"t]

Table 15.3
Estimated Total Solid Waste due to Concrete Production
(by Product and City)

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
20 MPa Ready Miixed [kg/m3]	49.07	49.27	49.27	49.25	49.90	50.24
30 MPa Ready Miixed [kg/m3]	49.24	49.54	49.54	49.50	50.44	50.94
60 MPa Ready Miixed [kg/m3]	50.06	50.41	50.41	50.37	51.49	52.08
Concrete Block [kg/block]	0.03	0.03	0.03	0.03	0.04	0.04
Cement Mortar [kg/m3]	3.51	3.81	3.81	3.78	4.75	5.27
Double T Beam [kg/m, 10' width]	2.28	2.78	2.78	2.72	4.32	5.18
Hollow Deck [kg/m, 4'w, 8"t]	1.95	2.45	2.45	2.39	4.00	4.85

the ATHENA™ Sustainable Materials Institute

CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE

Prepared by:

VENTA, GLASER & ASSOCIATES

Ottawa, Canada
October 1999

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Preface

This update to the October 1993 cradle-to-gate life cycle inventory report on cement and structural concrete products has been prepared for the ATHENA™ Sustainable Materials Institute as part of a continuing program to maintain the currency of data used in ATHENA™, the Institute's systems model for assessing the relative life cycle environmental implications of alternative building or assembly designs. The update is being issued to Institute members as an addendum to the original October 1993 report entitled *Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Cement and Structural Concrete Products* and should be used in conjunction with that report.

The integration of all the Institute's life cycle inventory data is a primary function of ATHENA™ itself and we therefore caution that individual industry life cycle study reports may not be entirely stand-alone documents in the sense that they tell the whole story about an individual set of products. For example, the original cement/concrete report and this addendum provide cradle-to-gate inventory data while other reports and databases cover the on-site construction, use, and demolition/disposal life cycle stages. ATHENA™ also generates various composite measures that can be best described as environmental impact indicators, a step toward the ultimate LCA goal of developing true measures of impacts on human and ecosystem health.

CONTENTS

CEMENT AND STRUCTURAL CONCRETE PRODUCTS: LIFE CYCLE INVENTORY UPDATE

1 Introduction

Venta, Glaser & Associates was commissioned by the Athena Institute to prepare this addendum to the October 1993 report entitled *Raw Material Balances, Energy Profiles and Environmental Unit Factor Estimates: Cement and Structural Concrete Products*. The purpose was to take account of changes in the structure and environmental performance of the Canadian cement and concrete industries in the years since the original report was issued. The original 1993 report was based primarily on 1991 data whereas this addendum relies on 1997/98 data.

The addendum follows the structure of, and should be used in conjunction with, the original report. Part I deals with cement production and Part II with production of the various structural concrete products used in buildings. Other than a few explanatory notes, the material provided here is in the mainly in the form of tables that replace corresponding tables in the original report. But the original still provides the descriptive and analytical material essential to understanding the industry and the various life cycle inventory estimates.

2 Part I: Cement Production

The cement data were revised according to information for 1998 provided by A. Cornelissen of the Canadian Portland Cement Association, supplemented by “Cement 1997” statistics from the Canadian Minerals Yearbook. The update data therefore represents the situation in the Canadian cement industry in 1997/98 period. Full references are given under Table 2.1 which follows the Part I explanatory notes.

The main differences between the data provided here and in the1993 report reflect either shifts in the relative production of the plants in the respective regions (West Coast, Prairie) or closure of some older wet kilns or complete plants (Beauport) in the Central and East regions. The revised tables are numbered the same as the corresponding tables in the original report and only tables that were changed are included in this addendum.

One important difference between industry operations in 1991 and 1997 is an increase in capacity utilization from about 59.2% in 1991 to 96% in 1997. This difference mainly affected the estimates of emissions to water from quarry operations, storm water run-off, and cement plant operations. The absolute amounts of these emissions are all relatively independent of capacity utilization, but the inventory results are expressed per unit of finished cement output which is obviously a direct function of capacity utilization.

Following are brief explanations of the changes to specific sections and tables in the original report related to cement production. The headings indicate the sections in the1993 report to which the notes refer. The revised tables follow the explanatory notes and have the same table numbers as in the original report.

2.1 Original Section 2

Table 2.1 was revised, reflecting the 1997/98 situation in the Canadian cement industry.

2.2 Original Section 3

Raw materials requirements and transportation in Tables 3.1 and 3.2 are unchanged. No direct information from the plants was solicited and we assumed no change in raw material inputs between 1991 and 1997.

2.3 Original Section 4

All energy input tables, i.e. 4.1 to 4.3 and 4.5 to 4.10 were revised taking into consideration basic changes in the industry, including relative shifts in market contributions among the plants (which affect weighted regional averages), the closure of some older wet kilns (St. Lawrence Cement in Mississauga and Ciment Quebec Inc. in St. Basile) and the closure of one complete plant (St. Lawrence Cement in Quebec City (Beauport)).

The changes in the West Coast and Prairie regions are small, reflecting only minor shifts in relative contributions of various operations and marginal increases in reported kiln capacities. But the closure of older and inefficient capacities in the Central and East regions resulted reduced manufacturing energy inputs (Tables 4.2-4.3).

We did not change Table 4.4, which shows manufacturing energy use estimates from various sources. However, CPCA states that the fuel efficiency of clinker production, which excludes electrical energy for clinker/gypsum grinding, dropped to 4.15 GJ/tonne of production in 1996 from 4.4 GJ/tonne in 1990.

Transportation distances/modes (Table 4.5) and resulting transportation energy for finished cement (Table 4.6) were slightly changed as a result of the changes in industry structure.

Tables 4.7-4.10 summarize the revised energy inputs.

2.4 Original Section 5

Changes in energy inputs cascade through and affect the emissions to air associated with cement production. As before, emissions due to electrical power usage are excluded because the Athena software assigns these according to the particular grid relevant to the region/city under consideration.

Tables 5.1-5.7 and 5.10-5.11 give revised estimates of emissions to air for various steps in cement production, from resource extraction to finished product transportation. CO_2, NO_x and SO_x emission estimates take account of calcination CO_2, thermal/prompt NO_x

and retained sulfur in the same manner and using the same assumptions as in the original study (Tables 5.5-5.7).

We did not change the NOx emission matrix (Table 5.8) for various types of cement kilns vs. different fossil fuels. We also assumed that the particulate emission factors (Table 5.9) remained the same because all the cement plants had already installed modern particulate collection systems before 1990 and were collecting virtually all of their particulate emissions.

CPCA suggests that the total CO_2 emissions per tonne of cement decreased by about 0.02 tonnes in 1996 compared to 1990, a decrease that closely matches our findings. The one region where we do not show a decrease of that order is the west coast. But for that region all of the energy use and emission estimates should have improved in 1999 with the opening of the new Lafarge precalciner plant in Richmond and the closing of the two wet kilns at that location.

2.5 Original Section 6

Both Tables 6.1 and 6.2 were revised, with the differences between 1991 and 1997 cement industry capacity utilization resulting in significant reductions in the emissions to water expressed in g/tonne of finished cement (Table 6.1). This is due to the fact that the cement quarry water, storm water run off, and much of the water use in the cement plant itself is independent of the level of capacity utilization. Since the industry operated at 96% capacity in 1997 compared to only about 59.2% in1991, similar discharge levels are spread over much higher cement output levels in the results presented here. Table 6.2 also shows modest reductions in the average absolute levels of quarry water effluents in 1997 compared to the original 1991 data.

2.6 Original Section 7

Table 7.3 was modified to reflect the shifts in the industry from the older wet kilns to more modern processes.

2.7 Original Section 8

In the original report, this section provided a summary by simply showing the key tables from all of the preceding sections. Since the revised tables are presented here in sequence without intervening text, a repeat of the original summary section is unnecessary.

2.8 Revised Tables

TABLE 2.1
1998 CANADIAN CEMENT PLANT LOCATIONS, KILN TYPES, KILN CAPACITIES AND OTHER EQUIPMENT

	Kilns (1,000t/y)				Grinding equipment		
Company and Location	Wet	Long Dry	Pre-heater	Pre-calciner	Roller mills	High efficiency separators	Roller presses
Tilbury Cement Ltd. Delta, BC			1146		1	2	
Lafarge Canada Inc. Richmond, BC	242 280					2	
Lafarge Canada Inc. Kamloops, BC		214					
Lafarge Canada Inc. Exshaw, AB		419		 715			
Inland Cement Ltd. Edmonton, AB				800	1		
Blue Circle Canada Inc. St. Mary, ON			711		1		1
Federal White Cement Ltd Woodstock, ON		189				1	1
Lafarge Canada Inc. Woodstock, ON	301 301						
St. Lawrence Cement Inc. Mississauga, ON				1452		1	
Blue Circle Canada Inc. Bowmanville, ON				1709	1	1	
ESSROC Canada Inc. Picton, ON		320	 919		2		
Lafarge Canada Inc. Bath, ON			1152			2	
Lafarge Canada Inc. St. Constant, PQ		546 546					
St. Lawrence Cement Inc. Joliette, PQ		273 273 273 273				1	
Climent Quebec Inc. St. Basile, PQ				814	1		1
Lafarge Canada Inc. Brookfield, NS		259 322					
North Star Cement Ltd. Corner Brook, NF			168			1	
Capacity Total: **14,617**	**1,124**	**3,907**	**4,096**	**5,490**			

Source: 1) CPCA, personal communications, fax from A. Cornelissen, Sept. 8, 1998.
2)"Cement 1997", Canadian Minerals Yearbook, NRCAN 1998.
3) Athena™ "Cement and Structural Concrete Products", Ottawa, 1993.

Note: new Lafarge Canada Inc., Richmond, BC plant is scheduled to open May 1999; wet kilns will shut down

Table 4.1
Weighted average energy use for raw materials extraction and transport
[GJ/tonne of finished cement]

Region	Extraction	Raw materials transportation				
	Diesel - road	Diesel - road	Diesel - rail	HFO - marine	Electricity	Total Transport
West Coast	0.04464	0.00755	0.00057	0.08167	0.00049	0.09028
Prairie	0.04455	0.03617	0.18853	0.00000	0.00077	0.22547
Central	0.04448	0.03072	0.00600	0.02820	0.00221	0.06716
East	0.04413	0.01537	0.00000	0.00742	0.00128	0.02406
Canada	0.04442	0.02452	0.02791	0.02602	0.00156	0.08003

Table 4.2
Weighted average energy use in manufacturing by process step
[GJ/tonne of finished cement]

Region	Process Step					
	Primary Crushing	Secondary Crushing	Raw Grinding	Pyro-processing	Finish Grinding	Total Manufacturing
West Coast	0.01785	0.03570	0.31310	4.17527	0.17256	4.71448
Prairie	0.01782	0.03564	0.33522	3.70824	0.20880	4.30572
Central	0.01779	0.03558	0.34322	3.66024	0.19634	4.25317
East	0.01765	0.03530	0.35747	4.63782	0.19473	5.24298
Canada	0.01777	0.03553	0.34194	3.98350	0.19451	4.57325

Table 4.3
Weighted average energy use in manufacturing by energy form
[GJ/tonne of finished cement]

Region	Energy Form						
	Nat. Gas	Coal	Oil	Coke	Waste	Electricity	Total
West Coast	2.32423	1.46504	0.15302	0.20140	0.00000	0.57079	4.71448
Prairie	3.66633	0.00000	0.00000	0.00000	0.00000	0.63939	4.30572
Central	0.61203	2.08826	0.09945	0.67028	0.16041	0.62274	4.25317
East	0.79923	1.71361	0.64573	1.13811	0.34821	0.59810	5.24298
Canada	1.28459	1.63568	0.23322	0.64115	0.16668	0.61194	4.57325

Table 4.5
Weighted average transportation distances and modes for finished cement
[km/tonne]

Region / City	Distance by Mode: Truck	Rail	Ship
West Coast			
Vancouver	115.72		
Prairie			
Calgary	316.48		
Winnipeg		2620.00	
Central			
Toronto	102.55		147.14
East			
Montreal	129.61	43.20	
Halifax	186.17		296.07

Table 4.6
Weighted average transportation energy for finished cement
[GJ/tonne]

Region / City	Energy Form: Diesel - road	Diesel - rail	HFO marine	Total
West Coast				
Vancouver	0.13655			0.13655
Prairie				
Calgary	0.37345			0.37345
Winnipeg		1.28380		1.28380
Central				
Toronto	0.12101		0.01766	0.13867
East				
Montreal	0.15294	0.02117		0.17411
Halifax	0.21968		0.03553	0.25521

Table 4.7
Weighted average energy use in cement production by process stage
[GJ/tonne of finished cement]

Region / City	Process Stage: Raw Materials Extraction	Raw Materials Transportation	Manufacturing	Cement Transportation	**TOTAL**
West Coast					
Vancouver	0.04464	0.09028	4.71448	0.13655	4.98595
Prairie					
Calgary	0.04455	0.22547	4.30572	0.37345	4.94920
Winnipeg	0.04455	0.22547	4.30572	1.28380	5.85954
Central					
Toronto	0.04448	0.06716	4.25317	0.13867	4.50347
East					
Montreal	0.04413	0.02406	5.24298	0.17411	5.48528
Halifax	0.04413	0.02406	5.24298	0.25521	5.56638

Table 4.8
Weighted average energy use in cement production by process stage
[%]

Region / City	Process Stage: Raw Materials Extraction	Raw Materials Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.90	1.81	94.56	2.74	100.00
Prairie					
Calgary	0.90	4.56	87.00	7.55	100.00
Winnipeg	0.76	3.85	73.48	21.91	100.00
Central					
Toronto	0.99	1.49	94.44	3.08	100.00
East					
Montreal	0.80	0.44	95.58	3.17	100.00
Halifax	0.79	0.43	94.19	4.58	100.00

Table 4.9
Weighted average pyroprocessing energy by process type

Process type	GJ/tonne
Wet	5.91889
Dry Long	5.09860
Dry Preheater	3.36187
Dry Precalciner	3.25748

Table 4.10
Weighted average energy use in cement production by energy form
[GJ/tonne of finished cement]

Region	Energy Form: Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	TOTAL
West Coast										
Vancouver	0.18874	0.00057	0.08167	2.32423	1.46504	0.15302	0.20140	0.00000	0.57129	4.98595
Prairie										
Calgary	0.45417	0.18853	0.00000	3.66633	0.00000	0.00000	0.00000	0.00000	0.64016	4.94919
Winnipeg	0.08072	1.47233	0.00000	3.66633	0.00000	0.00000	0.00000	0.00000	0.64016	5.85954
Central										
Toronto	0.19621	0.00600	0.04585	0.61203	2.08826	0.09945	0.67028	0.16041	0.62496	4.50345
East										
Montreal	0.21243	0.02117	0.00742	0.79923	1.71361	0.64573	1.13811	0.34821	0.59938	5.48528
Halifax	0.27917	0.00000	0.04294	0.79923	1.71361	0.64573	1.13811	0.34821	0.59938	5.56638

Table 5.1
Energy emissions factors
[kg/GJ]

	CO2	SO2	NOx	VOC	CH4	CO
natural gas	49.700	0.0002	0.0590	0.00120	0.00130	0.01500
diesel road	70.700	0.1020	0.8070	0.08690	0.02170	0.44300
diesel rail	70.700	0.1020	1.4000	0.07000	0.00780	0.05700
H.F. oil marine	74.000	0.4500	0.2000	0.36000	0.04000	0.00740
H.F.oil industr.	74.000	0.8375	0.1600	0.00290	0.00082	0.01440
coal - W.Coast	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
coal - Prairie	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
coal - Central	87.600	0.8360	0.2500	0.00150	0.00054	0.09300
coal - East	85.333	1.7278	0.2500	0.00150	0.00054	0.09300
coke	86.000	1.1500	0.2400	0.00140	0.00051	0.08800
waste	67.500		0.1200	0.00120	0.00110	

Table 5.2
Atmospheric emissions due to cement raw materials extraction
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	3156.06	4.55	36.02	3.88	0.97	19.78	843.20
Prairie	Calgary	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
	Winnipeg	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
Central	Toronto	3144.48	4.54	35.89	3.86	0.97	19.70	840.02
East	Montreal	3119.82	4.50	35.61	3.83	0.96	19.55	833.44
	Halifax	3119.82	4.50	35.61	3.83	0.96	19.55	833.44

Table 5.3
Atmospheric emissions due to cement raw materials transportation
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO
West Coast	Vancouver	6617.55	37.58	23.22	30.10	3.44	3.98
Prairie	Calgary	15886.12	22.92	293.13	16.34	2.26	26.77
	Winnipeg	15886.12	22.92	293.13	16.34	2.26	26.77
Central	Toronto	4683.06	16.43	38.84	13.24	1.84	14.16
East	Montreal	1635.07	4.90	13.88	4.00	0.63	6.86
	Halifax	1635.07	4.90	13.88	4.00	0.63	6.86

Table 5.4
Atmospheric emissions due to cement manufacturing
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	780645.95	39.01	4525.61	5.71	4.04	189.04	483.06
Prairie	Calgary	680551.58	0.06	5016.32	4.40	4.77	52.71	938.00
	Winnipeg	680551.58	0.06	5016.32	4.40	4.77	52.71	938.00
Central	Toronto	787514.91	100.91	2074.99	5.29	2.52	261.42	340.32
East	Montreal	853448.96	186.68	2979.57	7.41	3.46	278.24	863.23
	Halifax	853448.96	186.68	2979.57	7.41	3.46	278.24	603.00

Table 5.5
Fuel and calcination CO_2 emissions from cement manufacturing
[g/tonne of cement]

Region	City	Calcination CO2	Fuel Manufact. CO2	Total Manufact. CO2	Calcination as% of Total Manufact. CO2	Grand Total CO2
West Coast	Vancouver	498334.83	282311.12	780645.95	63.84	800073.40
Prairie	Calgary	498334.83	182216.75	680551.58	73.23	725990.38
	Winnipeg	498334.83	182216.75	680551.58	73.23	790352.05
Central	Toronto	498334.83	289180.08	787514.91	63.28	805204.62
East	Montreal	498334.83	355114.13	853448.96	58.39	870513.28
	Halifax	498334.83	355114.13	853448.96	58.39	876364.26

Table 5.6
SO_2 cement manufacturing emissions corrected as per Gagan
[g/tonne of cement]

Region	City	Pyroproces. Fuel SO2	Corrected Pyroproses. SO2	Corrected Ttl. Manufact. SO2	Corrected Grand Total SO2
West Coast	Vancouver	965.83	38.99	39.01	95.08
Prairie	Calgary	0.68	0.03	0.06	65.61
	Winnipeg	0.68	0.03	0.06	158.47
Central	Toronto	2499.10	100.88	100.91	142.17
East	Montreal	4623.79	186.64	186.68	213.84
	Halifax	4623.79	186.64	186.68	234.48

Table 5.7
NOx cement manufacturing emissions
[g/tonne of cement]

Region	City	Pyroprocess. NOx	Fuel NOx	Thermal and Prompt NOx	Total Manufact. NOx	Grand Total NOx
West Coast	Vancouver	4517.73	568.33	3949.40	4525.61	4695.05
Prairie	Calgary	5007.33	207.33	4800.01	5016.32	5646.77
	Winnipeg	5007.33	207.33	4800.01	5016.32	7142.72
Central	Toronto	2065.60	744.82	1320.79	2074.99	2250.90
East	Montreal	2969.47	883.71	2085.76	2979.57	3182.12
	Halifax	2969.47	883.71	2085.76	2979.57	3213.45

Table 5.10
Atmospheric emissions due to transportation of finished cement
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO
West Coast	Vancouver	9653.83	13.93	110.19	11.87	2.96	60.49
Prairie	Calgary	26402.99	38.09	301.38	32.45	8.10	165.44
	Winnipeg	90764.66	130.95	1797.32	89.87	10.01	73.18
Central	Toronto	9862.18	20.29	101.19	16.87	3.33	53.74
East	Montreal	12309.43	17.76	153.06	14.77	3.48	68.96
	Halifax	18160.41	38.40	184.39	31.88	6.19	97.58

Table 5.11
Total atmospheric emissions due to cement production
[g/tonne of cement]

Region	City	CO2	SO2	NOx	VOC	CH4	CO	TPM
West Coast	Vancouver	800073.40	95.08	4695.05	51.56	11.41	273.28	1326.26
Prairie	Calgary	725990.38	65.61	5646.77	57.06	16.09	264.66	1779.50
	Winnipeg	790352.05	158.47	7142.72	114.48	18.00	172.39	1779.50
Central	Toronto	805204.62	142.17	2250.90	39.26	8.66	349.02	1180.34
East	Montreal	870513.28	213.84	3182.12	30.03	8.53	373.61	1696.67
	Halifax	876364.26	234.48	3213.45	47.13	11.23	402.23	1436.44

Table 6.1
Liquid Effluent due to Production of Cement
[g/tonne of cement]

	Cement plant		**Quarry water**		**Stormwater**		**Total**
	wght. avg.	range	wght. avg.	range	wght. avg.	range	wght. avg.
Suspended Solids	72.17	10.94-108.49	51.86	8.50-203.65	0.40	6.24-45.72	124.43
Aluminum	0.29	0.02-0.61	0.17	0.00-0.29			0.46
Phenolics	0.00	0.00-0.01	0.00	0.00-0.01	0.00	0.00	0.01
Oil & Grease	2.59	0.94-5.31	1.42	0.14-6.84	0.00	0.00-0.29	4.02
Nitrate, Nitrite	0.86	0.16-2.48	2.19	0.14-6.21	0.00	0.08-0.55	3.05
DOC	4.96	0.17-8.39	2.41	0.05-9.32			7.37
Chlorides	83.32	21.39-197.78	290.52	8.82-676.57	0.58	1.33-48.07	374.43
Sulphates	154.16	24.93-486.40	169.13	33.73-575.77	0.59	2.00-46.54	323.89
Sulphides	0.01	0.00-0.05	0.03	0.00-0.19			0.04
Ammonia, -um			0.48	0.05-1.03			0.48
Phosphorus			0.00	0.00-0.01			0.00
Zinc	0.01	0.00-0.06	0.01	0.00-0.10			0.02

Note: assumes 96% industry utilization (1998)

Table 6.2
Liquid Effluent due to Production of Cement
[mg/L of effluent]

	Cement plant		**Quarry water**		**Stormwater**	
	wght. avg.	range	wght. avg.	range	wght. avg.	range
Suspended Solids	62.47	10.36-150.93	86.41	24.65-182.55	137.61	32.09-249.27
Aluminum	0.16	0.05-0.29	0.67	0.00-1.39		
Phenolics	0.00	0.00-0.01	0.01	0.00-0.03	0.00	0.00-0.01
Oil & Grease	1.42	1.19-2.41	1.53	0.74-2.55	0.67	0.00-1.49
Nitrate, Nitrite	0.41	0.00-0.56	2.74	0.13-6.77	1.96	0.42-5.26
DOC	2.65	0.45-4.99	2.29	0.13-4.67		
Chlorides	44.45	14.43-134.55	1109.15	8.63-3284.12	162.55	12.78-262.10
Sulphates	105.85	20.07-584.24	200.66	40.59-331.70	163.60	19.28-239.39
Sulphides	0.00	0.01-0.02	0.03	0.00-0.08		
Ammonia, -um			1.21	0.17-3.11		
Phosphorus			0.01	0.00-0.04		
Zinc	0.00	0.00-0.02	0.00	0.00-0.02		
pH	8.26	8.25-8.41	8.15	7.79-8.88	8.84	8.13-10.5

Table 7.3
Cement Kiln Dust (CKD) Discarded as Solid Waste

City	**CKD** %	**Total CKD** kg/t of cement	**Waste CKD** kg/t of cement
Vancouver	3.95	58.477	15.79
Calgary	1.87	27.626	7.46
Winnipeg	1.87	27.626	7.46
Toronto	2.06	30.439	8.22
Montreal	3.91	57.926	15.64
Halifax	4.10	60.721	16.39

3 Part II: Concrete Products

The revised cement estimates were cascaded through to develop corresponding life cycle inventory estimates for the structural concrete products incorporated in the Athena software. We assumed there were no changes in the inventory data for coarse and fine aggregates and supplementary cementing materials (SCM), and we assumed the same requirements for reinforcing steel components as in the original study.

One addition is the calculation of inventory data for 60 MPa concrete, using a mix design provided by CPCA. According to CPCA, this is the higher strength ready mixed concrete that would be used if the 30 MPa strength is not sufficient, for columns or bridge decks for example. CPCA further advised that 40 or 50 MPa concrete are considered specialty mixtures and are not often used.

As in the preceding section of this repot, the revised tables follow the explanatory notes.

3.1 Original Section 9

60 MPa concrete should be added to the list of the concrete products given in the introduction of this section.

3.2 Original Section 10

Revised Table 10.1 now includes the raw materials requirements for 60 MPa concrete as provided by CPCA. The 60 MPa (and higher strength) concrete often includes silica fume, a high performance by-product of the smelting process used to produce silicon metal and ferrosilicon alloys. as a supplementary cementing material.

Silica fume is an industrial by-product and, as in the case of fly ash, we have not attributed or allocated energy to its production. And since it is an extremely fine product, there is no need for further grinding/processing to make it suitable for use as a SCM.

Three North American producers of silica fume (information provided by Ming Zhang of NRCan and Nick Fagan of SKW, 2/19/99), one in Canada (Quebec) and two in the US (Ohio, West Virginia) have about an equal share of the business across the continent. The actual intercity mileage estimates between the points of origin, all in the eastern part of the continent, and the six cities under consideration in the study were used for the weighted average transportation calculations. We assumed that all the silica fume is transported by truck, 50% in bags with 100% backhaul and the other 50% in bulk, with no backhaul. This means that the actual transportation distances were multiplied by 1.5.

CPCA confirmed that there was no change (increase) in the use of SCM for the other strengths of ready mixed and the formulation of the other structural concrete products therefore remains unchanged.

3.3 Original Section 11

Following are the transportation energy estimates for silica fume, based on the assumptions described above:

City	Diesel – Road GJ/t
Vancouver	7.92582
Calgary	6.23512
Winnipeg	3.98557
Toronto	1.20454
Montreal	1.41978
Halifax	3.11426

Other raw material extraction, processing and transportation energy estimates remain the same as in the original study.

Tables 11.1 through 11.14 give updated energy use by process stage and/or fuel type for the six types of concrete products from the earlier study, with Tables 11.3A and 11.6A inserted to cover 60 MPa ready mixed concrete.

3.4 Original Section 12

There is no change to this section.

3.5 Original Section 13

Tables 13.1 and 13.2 remain unchanged. Atmospheric emissions due to the transportation of silica fume used in 60 MPa concrete are given in Table 13.2A.

The updated atmospheric emissions for the eight concrete products under consideration, are given in Tables 13.2-13.10 (note that a table has been added to the original series to cover 60MPa ready mixed).

3.6 Original Section 14

Tables 14.1-14.3 remain unchanged, while Tables 14.4-14.6 provide the updated effluent data. For the reasons discussed in Section 7, Part I, Tables 14.4 and 14.6 show lower emissions to water and pollutant flows in 1997 than in 1991.

3.7 Original Section 15

Data for a 60 MPa concrete was added to Tables 15.1-15.3.

3.8 Original Section 16

This section of the original report, which summarized the results by consolidating key tables from earlier sections, need not be repeated here.

3.9 Revised Tables

Table 10.1
Raw material requirements by concrete product
(kg/m^3)

RAW MATERIAL	15 MPa Ready Mixed	20 MPa Ready Mixed	30 MPa Ready Mixed	60 MPa Ready Mixed	Block	Double T Beam	Hollow Deck	Cement Mortar
Cement	191	218	319	352	189	505	505	307
Fly ash	19	22	31	-	-	-	-	-
Blast furnace slag								
Silica fume	-	-	-	33	-	-	-	-
Coarse aggregate	970	1009	1092	1088	510	750	750	-
Fine aggregate	963	925	722	748	1191	744	744	785
Water	160	160	160	165	53	202	202	185
Total	2303	2334	2324	2386	1943	2201	2201	1277

Sources: 1. 15 MPa, 20 MPa and 30 MPa ready mixed concrete - CPCA, private correspondence from L. Hamre, P.Eng., Building Science Engineer, November 15, 1993.
2. 60 MPa ready mixed concrete - CPCA, correspondence from A.Cornelissen, Manager-Building Science, September 8, 1998.
3. Block - J.L Schmidt, H. Bennett and W.H. Lewis, *Construction Principles, Materials and Methods* (ASLIP, Chicago, Ill., 1972).
4. Double T and hollow deck - same source as for ready mixed.
5. Cement Mortar - F.M. Lea, *The Chemistry of Cement and Concrete* (Chemical Publishing Company, Inc., New York, 1971), p. 531.

Table 11.1
Energy Use in 15 MPa Ready Mixed Concrete Production by Process Stage
[GJ/M3]

Region	Process Stage: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-total	Total
West Coast						
Vancouver	0.09498	0.07479	0.95232	0.23951	1.19183	1.36159
Prairie						
Calgary	0.09387	0.06461	0.94530	0.23951	1.18481	1.34328
Winnipeg	0.09387	0.05922	1.11917	0.23951	1.35868	1.51178
Central						
Toronto	0.09609	0.06747	0.86016	0.23951	1.09967	1.26324
East						
Montreal	0.09387	0.06380	1.04769	0.23951	1.28720	1.44487
Halifax	0.09387	0.05922	1.06318	0.23951	1.30269	1.45578

Table 11.2
Energy Use in 20 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.09437	0.07717	1.08694	0.24274	1.32967	1.50122
Prairie						
Calgary	0.09309	0.06538	1.07892	0.24274	1.32166	1.48013
Winnipeg	0.09309	0.05915	1.27738	0.24274	1.52012	1.67235
Central						
Toronto	0.09566	0.06871	0.98175	0.24274	1.22449	1.38885
East						
Montreal	0.09309	0.06446	1.19579	0.24274	1.43853	1.59607
Halifax	0.09309	0.05915	1.21347	0.24274	1.45621	1.60844

Table 11.3
Energy Use in 30 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.08598	0.08038	1.59052	0.24170	1.83221	1.99857
Prairie						
Calgary	0.08416	0.06377	1.57879	0.24170	1.82049	1.96842
Winnipeg	0.08416	0.05499	1.86919	0.24170	2.11089	2.25004
Central						
Toronto	0.08779	0.06845	1.43660	0.24170	1.67830	1.83454
East						
Montreal	0.08416	0.06246	1.74980	0.24170	1.99150	2.13812
Halifax	0.08416	0.05499	1.77567	0.24170	2.01737	2.15652

Table 11.3A
Energy Use in 60 MPa Ready Mixed Concrete Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.08556	0.29786	1.75505	0.24814	2.00320	2.38661
Prairie						
Calgary	0.08556	0.24544	1.74212	0.24814	1.99026	2.32126
Winnipeg	0.08556	0.17571	2.06256	0.24814	2.31070	2.57197
Central						
Toronto	0.08556	0.08950	1.58521	0.24814	1.83336	2.00841
East						
Montreal	0.08556	0.09617	1.93082	0.24814	2.17896	2.36069
Halifax	0.08556	0.14870	1.95936	0.24814	2.20751	2.44176

Table 11.4
Energy Use in 15 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.29143	0.01314	0.01925	0.48423	0.27982	0.06953	0.03847	0.00000	0.16572	1.36159
Prairie										
Calgary	0.34863	0.03601	0.00000	0.74057	0.00000	0.04030	0.00000	0.00000	0.17777	1.34328
Winnipeg	0.27192	0.28121	0.00000	0.74057	0.00000	0.04030	0.00000	0.00000	0.17777	1.51178
Central										
Toronto	0.30223	0.00115	0.00876	0.15720	0.39886	0.05930	0.12802	0.03064	0.17708	1.26324
East										
Montreal	0.29596	0.00404	0.00712	0.19295	0.32730	0.16364	0.21738	0.06651	0.16998	1.44487
Halifax	0.30983	0.00000	0.00820	0.19295	0.32730	0.16364	0.21738	0.06651	0.16998	1.45578

Table 11.5
Energy Use in 20 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.29826	0.01522	0.02203	0.54753	0.31938	0.07420	0.04391	0.00000	0.18070	1.50122
Prairie										
Calgary	0.36365	0.04110	0.00000	0.84011	0.00000	0.04085	0.00000	0.00000	0.19443	1.48013
Winnipeg	0.27601	0.32097	0.00000	0.84011	0.00000	0.04085	0.00000	0.00000	0.19443	1.67235
Central										
Toronto	0.31074	0.00131	0.01000	0.17427	0.45524	0.06252	0.14612	0.03497	0.19369	1.38885
East										
Montreal	0.30343	0.00461	0.00822	0.21508	0.37357	0.18161	0.24811	0.07591	0.18554	1.59607
Halifax	0.31927	0.00000	0.00936	0.21508	0.37357	0.18161	0.24811	0.07591	0.18554	1.60844

Table 11.6
Energy Use in 30 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.30876	0.02145	0.03201	0.78210	0.46735	0.08948	0.06425	0.00000	0.23318	1.99857
Prairie										
Calgary	0.40404	0.06014	0.00000	1.21023	0.00000	0.04067	0.00000	0.00000	0.25334	1.96842
Winnipeg	0.27613	0.46967	0.00000	1.21023	0.00000	0.04067	0.00000	0.00000	0.25334	2.25004
Central										
Toronto	0.32643	0.00191	0.01463	0.23591	0.66616	0.07239	0.21382	0.05117	0.25212	1.83454
East										
Montreal	0.31631	0.00675	0.01167	0.29562	0.54664	0.24666	0.36306	0.11108	0.24033	2.13812
Halifax	0.33943	0.00000	0.01370	0.29562	0.54664	0.24666	0.36306	0.11108	0.24033	2.15652

Table 11.6A
Energy Use in 60 MPa Ready Mixed Concrete Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.56418	0.00020	0.02875	0.85988	0.51569	0.09562	0.07089	0.00000	0.25139	2.38661
Prairie										
Calgary	0.60520	0.06636	0.00000	1.33230	0.00000	0.04176	0.00000	0.00000	0.27564	2.32126
Winnipeg	0.40401	0.51826	0.00000	1.33230	0.00000	0.04176	0.00000	0.00000	0.27564	2.57197
Central										
Toronto	0.35845	0.00211	0.01614	0.25719	0.73507	0.07676	0.23594	0.05647	0.27029	2.00841
East										
Montreal	0.37083	0.00745	0.00261	0.32308	0.60319	0.26905	0.40061	0.12257	0.26128	2.36069
Halifax	0.44686	0.00000	0.01512	0.32308	0.60319	0.26905	0.40061	0.12257	0.26128	2.44176

Table 11.7
Energy Use in Concrete Block Production by Process Stage
[GJ/block]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing			
			Cement	Processing	Sub-total	
West Coast						
Vancouver	0.00087	0.00052	0.00906	0.01241	0.02147	0.02285
Prairie						
Calgary	0.00087	0.00052	0.00899	0.01241	0.02140	0.02279
Winnipeg	0.00087	0.00052	0.01065	0.01241	0.02305	0.02444
Central						
Toronto	0.00087	0.00052	0.00818	0.01241	0.02059	0.02198
East						
Montreal	0.00087	0.00052	0.00997	0.01241	0.02237	0.02376
Halifax	0.00087	0.00052	0.01012	0.01241	0.02252	0.02391

Table 11.8
Energy Use Concrete Block Production by Energy Form
[GJ/block]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.00368	0.00000	0.00015	0.01306	0.00266	0.00028	0.00037	0.00000	0.00266	0.02285
Prairie										
Calgary	0.00416	0.00034	0.00000	0.01550	0.00000	0.00000	0.00000	0.00000	0.00278	0.02279
Winnipeg	0.00348	0.00268	0.00000	0.01550	0.00000	0.00000	0.00000	0.00000	0.00278	0.02444
Central										
Toronto	0.00369	0.00001	0.00008	0.00995	0.00380	0.00018	0.00122	0.00029	0.00276	0.02198
East										
Montreal	0.00372	0.00004	0.00001	0.01029	0.00311	0.00117	0.00207	0.00063	0.00271	0.02376
Halifax	0.00384	0.00000	0.00008	0.01029	0.00311	0.00117	0.00207	0.00063	0.00271	0.02391

Table 11.9
Energy Use in Cement Mortar Production by Process Stage
[GJ/m3]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.04663	0.02779	1.53069	0.00395	1.53464	1.60905
Prairie						
Calgary	0.04663	0.02779	1.51940	0.00395	1.52335	1.59777
Winnipeg	0.04663	0.02779	1.79888	0.00395	1.80283	1.87725
Central						
Toronto	0.04663	0.02779	1.38256	0.00395	1.38651	1.46093
East						
Montreal	0.04663	0.02779	1.68398	0.00395	1.68793	1.76235
Halifax	0.04663	0.02779	1.70888	0.00395	1.71283	1.78725

Table 11.10
Energy Use Cement Mortar Production by Energy Form
[GJ/m3]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.10693	0.00017	0.02507	0.71354	0.44977	0.04698	0.06183	0.00000	0.20477	1.60905
Prairie										
Calgary	0.18842	0.05788	0.00000	1.12556	0.00000	0.00000	0.00000	0.00000	0.22591	1.59777
Winnipeg	0.07377	0.45200	0.00000	1.12556	0.00000	0.00000	0.00000	0.00000	0.22591	1.87725
Central										
Toronto	0.10922	0.00184	0.01408	0.18789	0.64110	0.03053	0.20577	0.04925	0.22125	1.46093
East										
Montreal	0.11420	0.00650	0.00228	0.24536	0.52608	0.19824	0.34940	0.10690	0.21339	1.76235
Halifax	0.13469	0.00000	0.01318	0.24536	0.52608	0.19824	0.34940	0.10690	0.21339	1.78725

Table 11.11
Energy Use in Double T Beam Production by Process Stage
[GJ/metre of 10' wide beam]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-total	
West Coast						
Vancouver	0.02154	0.01792	0.74761	0.14482	0.89243	0.93189
Prairie						
Calgary	0.02154	0.01792	0.74209	0.14482	0.88692	0.92638
Winnipeg	0.02154	0.01792	0.87859	0.14482	1.02342	1.06288
Central						
Toronto	0.02154	0.01792	0.67526	0.14482	0.82008	0.85955
East						
Montreal	0.02154	0.01792	0.82248	0.14482	0.96730	1.00676
Halifax	0.02154	0.01792	0.83464	0.14482	0.97946	1.01893

Table 11.12
Energy Use in Hollow Deck Production by Process Stage
[GJ/metre of 4' wide by 8" deep slab]

Region	Process Stage					Total
	Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-total	
West Coast						
Vancouver	0.01233	0.01033	0.42804	0.08292	0.51096	0.53363
Prairie						
Calgary	0.01233	0.01033	0.42489	0.08292	0.50781	0.53047
Winnipeg	0.01233	0.01033	0.50304	0.08292	0.58596	0.60863
Central						
Toronto	0.01233	0.01033	0.38662	0.08292	0.46954	0.49221
East						
Montreal	0.01233	0.01033	0.47091	0.08292	0.55383	0.57650
Halifax	0.01233	0.01033	0.47787	0.08292	0.56079	0.58346

Table 11.13
Energy Use in Double T Beam Production by Energy Form
[GJ/metre of 10' wide beam]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.07911	0.00008	0.01225	0.44693	0.21967	0.02294	0.03020	0.00000	0.12071	0.93189
Prairie										
Calgary	0.11891	0.02827	0.00000	0.64816	0.00000	0.00000	0.00000	0.00000	0.13104	0.92638
Winnipeg	0.06292	0.22076	0.00000	0.64816	0.00000	0.00000	0.00000	0.00000	0.13104	1.06288
Central										
Toronto	0.08023	0.00090	0.00688	0.19019	0.31312	0.01491	0.10050	0.02405	0.12876	0.85955
East										
Montreal	0.08267	0.00317	0.00111	0.21826	0.25694	0.09682	0.17065	0.05221	0.12492	1.00676
Halifax	0.09267	0.00000	0.00644	0.21826	0.25694	0.09682	0.17065	0.05221	0.12492	1.01893

Table 11.14
Energy Use in Hollow Deck Production by Energy Form
[GJ/metre of 4' wide by 8" deep slab]

Region	Energy Form									Total
	Diesel road	Diesel rail	HFO marine	Natural Gas	Coal	Oil	Coke	Waste	Electricity	
West Coast										
Vancouver	0.04537	0.00005	0.00701	0.25589	0.12577	0.01314	0.01729	0.00000	0.06911	0.53363
Prairie										
Calgary	0.06815	0.01618	0.00000	0.37111	0.00000	0.00000	0.00000	0.00000	0.07503	0.53047
Winnipeg	0.03609	0.12640	0.00000	0.37111	0.00000	0.00000	0.00000	0.00000	0.07503	0.60863
Central										
Toronto	0.04601	0.00052	0.00394	0.10890	0.17928	0.00854	0.05754	0.01377	0.07372	0.49221
East										
Montreal	0.04740	0.00182	0.00064	0.12497	0.14711	0.05544	0.09771	0.02989	0.07152	0.57650
Halifax	0.05313	0.00000	0.00369	0.12497	0.14711	0.05544	0.09771	0.02989	0.07152	0.58346

Table 13.2A
Atmospheric Emissions due to Transportation of Silica Fume

City	CO2 [kg/tonne]	SO2 [g/tonne]	NOx [g/tonne]	VOC [g/tonne]	CH4 [g/tonne]	CO [g/tonne]
Vancouver	560.3558	0.8084	6.3961	0.6888	0.1720	3.5111
Calgary	440.8230	0.6360	5.0317	0.5418	0.1353	2.7622
Winnipeg	74.6856	4.0876	4.7926	4.0725	4.0073	4.4286
Toronto	85.1613	0.1229	0.9721	0.1047	0.0261	0.5336
Montreal	100.3782	0.1448	1.1458	0.1234	0.0308	0.6290
Halifax	220.1779	0.3177	2.5132	0.2706	0.0676	1.3796

Table 13.3
Atmospheric Emissions due to 15 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Prairie	Calgary	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
	Winnipeg	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Central	Toronto	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
East	Montreal	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
	Halifax	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Raw Material Transportation								
West Coast	Vancouver	5299.35	8.90	65.87	7.27	1.51	26.51	
Prairie	Calgary	4567.57	6.59	52.14	5.61	1.40	28.62	
	Winnipeg	4187.15	6.04	47.79	5.15	1.29	26.24	
Central	Toronto	4770.47	6.88	54.45	5.86	1.46	29.89	
East	Montreal	4529.70	8.49	48.03	7.10	1.49	25.78	
	Halifax	4187.15	6.04	47.79	5.15	1.29	26.24	
Concrete Processing								
West Coast	Vancouver	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Prairie	Calgary	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
	Winnipeg	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Central	Toronto	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
East	Montreal	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
	Halifax	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Cement Production								
West Coast	Vancouver	152814.02	18.16	896.75	9.85	2.18	52.20	253.32
Prairie	Calgary	138664.16	12.53	1078.53	10.90	3.07	50.55	339.88
	Winnipeg	150957.24	30.27	1364.26	21.87	3.44	32.93	339.88
Central	Toronto	153794.08	27.15	429.92	7.50	1.65	66.66	225.45
East	Montreal	166268.04	40.84	607.78	5.73	1.63	71.36	324.06
	Halifax	167385.57	44.79	613.77	9.00	2.15	76.83	274.36
Processing Sub-total								
West Coast	Vancouver	168020.96	37.92	1018.72	22.53	5.39	117.70	373.32
Prairie	Calgary	153871.10	32.29	1200.50	23.58	6.28	116.05	459.88
	Winnipeg	166164.18	50.02	1486.22	34.55	6.65	98.43	459.88
Central	Toronto	169001.02	46.91	551.89	20.18	4.86	132.17	345.45
East	Montreal	181474.98	60.60	729.75	18.42	4.84	136.86	444.06
	Halifax	182592.51	64.54	735.73	21.68	5.35	142.33	394.36
TOTAL								
West Coast	Vancouver	177010.21	52.14	1126.70	34.34	8.03	167.33	469.97
Prairie	Calgary	162128.58	44.20	1294.75	33.73	8.82	167.79	556.53
	Winnipeg	174041.24	61.39	1576.13	44.23	9.06	147.79	556.53
Central	Toronto	177461.39	59.12	648.46	30.58	7.46	185.18	442.10
East	Montreal	189694.58	74.42	819.90	30.05	7.46	185.77	540.71
	Halifax	190469.57	75.91	825.64	31.37	7.77	191.69	491.01

Table 13.4
Atmospheric Emissions due to 20 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Prairie	Calgary	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Winnipeg	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Central	Toronto	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
East	Montreal	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Halifax	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Raw Material Transportation								
West Coast	Vancouver	5469.96	9.34	68.66	7.60	1.54	26.52	
Prairie	Calgary	4622.63	6.67	52.76	5.68	1.42	28.97	
	Winnipeg	4182.15	6.03	47.74	5.14	1.28	26.20	
Central	Toronto	4857.56	7.01	55.45	5.97	1.49	30.44	
East	Montreal	4578.78	8.87	48.01	7.40	1.52	25.68	
	Halifax	4182.15	6.03	47.74	5.14	1.28	26.20	
Concrete Processing								
West Coast	Vancouver	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Prairie	Calgary	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Winnipeg	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Central	Toronto	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
East	Montreal	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Halifax	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Cement Production								
West Coast	Vancouver	174416.00	20.73	1023.52	11.24	2.49	59.58	289.13
Prairie	Calgary	158265.90	14.30	1231.00	12.44	3.51	57.69	387.93
	Winnipeg	172296.75	34.55	1557.11	24.96	3.92	37.58	387.93
Central	Toronto	175534.61	30.99	490.70	8.56	1.89	76.09	257.32
East	Montreal	189771.89	46.62	693.70	6.55	1.86	81.45	369.87
	Halifax	191047.41	51.12	700.53	10.28	2.45	87.69	313.14
Processing Sub-total								
West Coast	Vancouver	189827.64	40.75	1147.13	24.09	5.74	125.96	409.13
Prairie	Calgary	173677.54	34.33	1354.60	25.29	6.76	124.08	507.93
	Winnipeg	187708.38	54.57	1680.72	37.81	7.17	103.97	507.93
Central	Toronto	190946.24	51.02	614.30	21.41	5.14	142.47	377.32
East	Montreal	205183.53	66.64	817.31	19.40	5.11	147.83	489.87
	Halifax	206459.04	71.14	824.14	23.13	5.70	154.07	433.14
TOTAL								
West Coast	Vancouver	198989.41	55.42	1257.93	36.23	8.41	175.61	505.83
Prairie	Calgary	181991.99	46.32	1449.51	35.51	9.31	176.18	604.63
	Winnipeg	195582.34	65.93	1770.59	47.49	9.59	153.30	604.63
Central	Toronto	199495.62	63.35	711.89	31.92	7.76	196.04	474.02
East	Montreal	213454.12	80.84	907.46	31.34	7.76	196.64	586.57
	Halifax	214333.00	82.50	914.01	32.80	8.12	203.41	529.84

Table 13.5
Atmospheric Emissions due to 30 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO_2	SO_2	NOx	VOC	CH_4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Prairie	Calgary	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Winnipeg	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Central	Toronto	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
East	Montreal	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Halifax	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Raw Material Transportation								
West Coast	Vancouver	5702.30	10.27	73.86	8.25	1.56	24.81	
Prairie	Calgary	4508.34	6.50	51.46	5.54	1.38	28.25	
	Winnipeg	3887.65	5.61	44.38	4.78	1.19	24.36	
Central	Toronto	4839.38	6.98	55.24	5.95	1.49	30.32	
East	Montreal	4446.54	9.61	44.76	7.97	1.53	23.62	
	Halifax	3887.65	5.61	44.38	4.78	1.19	24.36	
Concrete Processing								
West Coast	Vancouver	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Prairie	Calgary	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Winnipeg	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Central	Toronto	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
East	Montreal	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Halifax	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Cement Production								
West Coast	Vancouver	255223.41	30.33	1497.72	16.45	3.64	87.18	423.08
Prairie	Calgary	231590.93	20.93	1801.32	18.20	5.13	84.43	567.66
	Winnipeg	252122.30	50.55	2278.53	36.52	5.74	54.99	567.66
Central	Toronto	256860.27	45.35	718.04	12.53	2.76	111.34	376.53
East	Montreal	277693.74	68.22	1015.10	9.58	2.72	119.18	541.24
	Halifax	279560.20	74.80	1025.09	15.04	3.58	128.31	458.22
Processing Sub-total								
West Coast	Vancouver	270569.02	50.27	1620.80	29.24	6.88	153.28	543.08
Prairie	Calgary	246936.54	40.87	1924.40	31.00	8.37	150.53	687.66
	Winnipeg	267467.91	70.49	2401.60	49.31	8.98	121.09	687.66
Central	Toronto	272205.88	65.29	841.11	25.32	6.00	177.44	496.53
East	Montreal	293039.34	88.15	1138.17	22.37	5.96	185.28	661.24
	Halifax	294905.80	94.74	1148.17	27.83	6.82	194.41	578.22
TOTAL								
West Coast	Vancouver	279734.06	65.53	1734.18	41.75	9.50	199.78	633.78
Prairie	Calgary	254907.62	52.37	2015.38	40.80	10.82	200.47	778.36
	Winnipeg	274818.30	81.09	2485.50	58.35	11.24	167.15	778.36
Central	Toronto	280508.00	77.27	935.88	35.53	8.55	229.46	587.23
East	Montreal	300948.63	102.76	1222.46	34.60	8.55	230.60	751.94
	Halifax	302256.20	105.34	1232.07	36.87	9.08	240.47	668.92

Table 13.5A
Atmospheric Emissions due to 60 MPa Ready Mixed Concrete Production by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Prairie	Calgary	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
	Winnipeg	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Central	Toronto	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
East	Montreal	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
	Halifax	3504.74	5.06	40.00	4.31	1.08	21.96	90.70
Raw Material Transportation								
West Coast	Vancouver	21058.46	30.38	240.37	25.88	6.46	131.95	
Prairie	Calgary	17352.94	25.04	198.07	21.33	5.33	108.73	
	Winnipeg	12422.60	17.92	141.80	15.27	3.81	77.84	
Central	Toronto	6327.43	9.13	72.22	7.78	1.94	39.65	
East	Montreal	6799.15	9.81	77.61	8.36	2.09	42.60	
	Halifax	10512.94	15.17	120.00	12.92	3.23	65.87	
Concrete Processing								
West Coast	Vancouver	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Prairie	Calgary	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
	Winnipeg	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Central	Toronto	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
East	Montreal	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
	Halifax	15755.00	20.47	126.36	13.14	3.32	67.86	120.00
Cement Production								
West Coast	Vancouver	255223.41	30.33	1497.72	16.45	3.64	87.18	423.08
Prairie	Calgary	231590.93	20.93	1801.32	18.20	5.13	84.43	567.66
	Winnipeg	252122.30	50.55	2278.53	36.52	5.74	54.99	567.66
Central	Toronto	256860.27	45.35	718.04	12.53	2.76	111.34	376.53
East	Montreal	277693.74	68.22	1015.10	9.58	2.72	119.18	541.24
	Halifax	279560.20	74.80	1025.09	15.04	3.58	128.31	458.22
Processing Sub-total								
West Coast	Vancouver	270978.41	50.80	1624.08	29.58	6.96	155.04	543.08
Prairie	Calgary	247345.93	41.40	1927.68	31.34	8.46	152.29	687.66
	Winnipeg	267877.30	71.02	2404.89	49.66	9.07	122.86	687.66
Central	Toronto	272615.27	65.82	844.40	25.66	6.09	179.20	496.53
East	Montreal	293448.73	88.68	1141.46	22.72	6.04	187.05	661.24
	Halifax	295315.20	95.27	1151.45	28.17	6.91	196.18	578.22
TOTAL								
West Coast	Vancouver	295541.61	86.24	1904.45	59.78	14.50	308.95	633.78
Prairie	Calgary	268203.61	71.49	2165.76	56.98	14.86	282.98	778.36
	Winnipeg	283804.64	94.00	2586.69	69.23	13.95	222.66	778.36
Central	Toronto	282447.44	80.01	956.63	37.75	9.10	240.81	587.23
East	Montreal	303752.62	103.55	1259.07	35.38	9.21	251.61	751.94
	Halifax	309332.88	115.49	1311.45	45.40	11.21	284.01	668.92

Table 13.6
Atmospheric Emissions due to Concrete Block Production
by Process Stage and Region
[grams/block]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Prairie	Calgary	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Winnipeg	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Central	Toronto	31.22	0.05	0.36	0.04	0.01	0.20	0.82
East	Montreal	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Halifax	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Raw Material Transportation								
West Coast	Vancouver	36.84	0.05	0.42	0.05	0.01	0.23	
Prairie	Calgary	36.84	0.05	0.42	0.05	0.01	0.23	
	Winnipeg	36.84	0.05	0.42	0.05	0.01	0.23	
Central	Toronto	36.84	0.05	0.42	0.05	0.01	0.23	
East	Montreal	36.84	0.05	0.42	0.05	0.01	0.23	
	Halifax	36.84	0.05	0.42	0.05	0.01	0.23	
Concrete Processing								
West Coast	Vancouver	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Prairie	Calgary	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Winnipeg	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Central	Toronto	606.94	0.24	2.44	0.22	0.06	1.18	1.15
East	Montreal	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Halifax	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Cement Production								
West Coast	Vancouver	1453.97	0.17	8.53	0.09	0.02	0.50	2.41
Prairie	Calgary	1319.34	0.12	10.26	0.10	0.03	0.48	3.23
	Winnipeg	1436.31	0.29	12.98	0.21	0.03	0.31	3.23
Central	Toronto	1463.30	0.26	4.09	0.07	0.02	0.63	2.15
East	Montreal	1581.98	0.39	5.78	0.05	0.02	0.68	3.08
	Halifax	1592.62	0.43	5.84	0.09	0.02	0.73	2.61
Processing Sub-total								
West Coast	Vancouver	2060.92	0.42	10.97	0.31	0.08	1.68	3.56
Prairie	Calgary	1926.29	0.36	12.70	0.32	0.09	1.66	4.39
	Winnipeg	2043.25	0.53	15.42	0.42	0.10	1.50	4.39
Central	Toronto	2070.24	0.50	6.53	0.29	0.08	1.82	3.30
East	Montreal	2188.93	0.63	8.22	0.27	0.08	1.86	4.24
	Halifax	2199.56	0.67	8.28	0.30	0.08	1.91	3.76
TOTAL								
West Coast	Vancouver	2128.98	0.51	11.75	0.39	0.10	2.11	4.38
Prairie	Calgary	1994.35	0.46	13.47	0.40	0.11	2.09	5.21
	Winnipeg	2111.32	0.63	16.19	0.51	0.12	1.92	5.21
Central	Toronto	2138.31	0.60	7.30	0.37	0.10	2.24	4.12
East	Montreal	2256.99	0.73	9.00	0.36	0.10	2.29	5.05
	Halifax	2267.63	0.77	9.05	0.39	0.10	2.34	4.58

Table 13.7
Atmospheric Emissions due to Cement Mortar Production
by Process Stage and Region
[grams/m3]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Prairie	Calgary	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Winnipeg	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Central	Toronto	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
East	Montreal	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Halifax	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Raw Material Transportation								
West Coast	Vancouver	1964.68	2.83	22.43	2.41	0.60	12.31	
Prairie	Calgary	1964.68	2.83	22.43	2.41	0.60	12.31	
	Winnipeg	1964.68	2.83	22.43	2.41	0.60	12.31	
Central	Toronto	1964.68	2.83	22.43	2.41	0.60	12.31	
East	Montreal	1964.68	2.83	22.43	2.41	0.60	12.31	
	Halifax	1964.68	2.83	22.43	2.41	0.60	12.31	
Concrete Processing								
West Coast	Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Prairie	Calgary	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Winnipeg	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Central	Toronto	0.00	0.00	0.00	0.00	0.00	0.00	120.00
East	Montreal	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Halifax	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Cement Production								
West Coast	Vancouver	245622.53	29.19	1441.38	15.83	3.50	83.90	407.16
Prairie	Calgary	222879.05	20.14	1733.56	17.52	4.94	81.25	546.31
	Winnipeg	242638.08	48.65	2192.81	35.14	5.53	52.92	546.31
Central	Toronto	247197.82	43.65	691.03	12.05	2.66	107.15	362.37
East	Montreal	267247.58	65.65	976.91	9.22	2.62	114.70	520.88
	Halifax	269043.83	71.99	986.53	14.47	3.45	123.48	440.99
Processing Sub-total								
West Coast	Vancouver	245622.53	29.19	1441.38	15.83	3.50	83.90	527.16
Prairie	Calgary	222879.05	20.14	1733.56	17.52	4.94	81.25	666.31
	Winnipeg	242638.08	48.65	2192.81	35.14	5.53	52.92	666.31
Central	Toronto	247197.82	43.65	691.03	12.05	2.66	107.15	482.37
East	Montreal	267247.58	65.65	976.91	9.22	2.62	114.70	640.88
	Halifax	269043.83	71.99	986.53	14.47	3.45	123.48	560.99
TOTAL								
West Coast	Vancouver	249085.70	34.18	1480.91	20.08	4.57	105.60	566.41
Prairie	Calgary	226342.22	25.14	1773.09	21.78	6.00	102.95	705.56
	Winnipeg	246101.25	53.65	2232.34	39.40	6.59	74.62	705.56
Central	Toronto	250660.99	48.64	730.56	16.31	3.72	128.85	521.62
East	Montreal	270710.74	70.65	1016.44	13.47	3.68	136.40	680.13
	Halifax	272507.00	76.98	1026.06	18.73	4.51	145.18	600.24

Table 13.8
Atmospheric Emissions due to Double T Beam Production
by Process Stage and Region
[grams/metre of 10' wide beam]

		CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Prairie	Calgary	846.77	1.22	9.67	1.04	0.26	5.31	22.18
	Winnipeg	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Central	Toronto	846.77	1.22	9.67	1.04	0.26	5.31	22.18
East	Montreal	846.77	1.22	9.67	1.04	0.26	5.31	22.18
	Halifax	846.77	1.22	9.67	1.04	0.26	5.31	22.18
Raw Material Transportation								
West Coast	Vancouver	1267.28	1.83	14.47	1.56	0.39	7.94	
Prairie	Calgary	1267.28	1.83	14.47	1.56	0.39	7.94	
	Winnipeg	1267.28	1.83	14.47	1.56	0.39	7.94	
Central	Toronto	1267.28	1.83	14.47	1.56	0.39	7.94	
East	Montreal	1267.28	1.83	14.47	1.56	0.39	7.94	
	Halifax	1267.28	1.83	14.47	1.56	0.39	7.94	
Concrete Processing								
West Coast	Vancouver	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Prairie	Calgary	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
	Winnipeg	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Central	Toronto	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
East	Montreal	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
	Halifax	6370.21	2.15	22.68	1.94	0.58	10.74	35.63
Cement Production								
West Coast	Vancouver	119965.07	14.26	703.99	7.73	1.71	40.98	198.86
Prairie	Calgary	108856.87	9.84	846.69	8.56	2.41	39.68	266.82
	Winnipeg	118507.43	23.76	1071.00	17.16	2.70	25.85	266.82
Central	Toronto	120734.46	21.32	337.51	5.89	1.30	52.33	176.98
East	Montreal	130527.01	32.06	477.14	4.50	1.28	56.02	254.40
	Halifax	131404.32	35.16	481.83	7.07	1.68	60.31	215.38
Processing Sub-total								
West Coast	Vancouver	126335.28	16.41	726.67	9.67	2.29	51.72	234.49
Prairie	Calgary	115227.08	11.99	869.38	10.49	2.99	50.42	302.45
	Winnipeg	124877.64	25.91	1093.68	19.10	3.28	36.59	302.45
Central	Toronto	127104.67	23.47	360.19	7.82	1.88	63.07	212.61
East	Montreal	136897.22	34.22	499.82	6.44	1.86	66.76	290.03
	Halifax	137774.53	37.31	504.52	9.00	2.27	71.05	251.01
TOTAL								
West Coast	Vancouver	128449.33	19.46	750.80	12.26	2.94	64.96	256.67
Prairie	Calgary	117341.13	15.04	893.51	13.09	3.64	63.67	324.63
	Winnipeg	126991.69	28.96	1117.81	21.70	3.93	49.84	324.63
Central	Toronto	129218.72	26.52	384.32	10.42	2.53	76.32	234.79
East	Montreal	139011.27	37.27	523.95	9.04	2.51	80.01	312.21
	Halifax	139888.58	40.36	528.65	11.60	2.91	84.30	273.19

Table 13.9
Atmospheric Emissions due to Hollow Deck Production
by Process Stage and Region
[grams/metre of 4' wide by 8" deep slab]

		CO2	SO2	NOx	VOC	CH4	CO	TPM
Raw Material Extraction & Processing								
West Coast	Vancouver	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Prairie	Calgary	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Winnipeg	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Central	Toronto	484.82	0.70	5.53	0.60	0.15	3.04	12.70
East	Montreal	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Halifax	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Raw Material Transportation								
West Coast	Vancouver	730.49	1.05	8.34	0.90	0.22	4.58	
Prairie	Calgary	730.49	1.05	8.34	0.90	0.22	4.58	
	Winnipeg	730.49	1.05	8.34	0.90	0.22	4.58	
Central	Toronto	730.49	1.05	8.34	0.90	0.22	4.58	
East	Montreal	730.49	1.05	8.34	0.90	0.22	4.58	
	Halifax	730.49	1.05	8.34	0.90	0.22	4.58	
Concrete Processing								
West Coast	Vancouver	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Prairie	Calgary	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Winnipeg	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Central	Toronto	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
East	Montreal	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Halifax	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Cement Production								
West Coast	Vancouver	68686.30	8.16	403.07	4.43	0.98	23.46	113.86
Prairie	Calgary	62326.27	5.63	484.78	4.90	1.38	22.72	152.77
	Winnipeg	67851.72	13.60	613.20	9.83	1.55	14.80	152.77
Central	Toronto	69126.82	12.21	193.24	3.37	0.74	29.96	101.33
East	Montreal	74733.56	18.36	273.18	2.58	0.73	32.07	145.66
	Halifax	75235.87	20.13	275.87	4.05	0.96	34.53	123.32
Processing Sub-total								
West Coast	Vancouver	72333.58	9.39	416.06	5.53	1.31	29.61	134.26
Prairie	Calgary	65973.56	6.87	497.76	6.01	1.71	28.87	173.17
	Winnipeg	71499.00	14.84	626.19	10.94	1.88	20.95	173.17
Central	Toronto	72774.10	13.44	206.23	4.48	1.08	36.11	121.73
East	Montreal	78380.85	19.59	286.17	3.69	1.07	38.22	166.06
	Halifax	78883.15	21.36	288.86	5.15	1.30	40.68	143.72
TOTAL								
West Coast	Vancouver	73548.89	11.15	429.93	7.03	1.69	37.23	146.96
Prairie	Calgary	67188.87	8.62	511.63	7.50	2.09	36.49	185.87
	Winnipeg	72714.32	16.59	640.06	12.43	2.25	28.56	185.87
Central	Toronto	73989.41	15.19	220.10	5.97	1.45	43.73	134.43
East	Montreal	79596.16	21.34	300.04	5.18	1.44	45.84	178.76
	Halifax	80098.46	23.12	302.73	6.65	1.67	48.30	156.42

Table 14.4
Estimated Effluent Flows by Concrete Product
(liters/m3 of concrete)

	15MPa Ready Mixed	20MPa Ready Mixed	30MPa Ready Mixed	60MPa Ready Mixed	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Cement plant water	382.61	436.69	639.01	705.12	378.60	614.97	1011.60	1011.60
Quarry water	194.33	221.80	324.56	358.13	192.29	312.35	513.80	513.80
Stormwater	0.35	0.39	0.58	0.64	0.34	0.56	0.91	0.91
Aggregate quarry water	468.12	454.26	426.07	431.24	399.53	184.38	350.91	350.91
Concrete process water	50.00	50.00	50.00	50.00	12.50	25.00	12.50	12.50
Totals	1095.39	1163.14	1440.22	1545.13	983.26	1137.26	1889.72	1889.72
Total liters per block or metre					9.45		561.09	321.25

Table 14.5
Weighted Average Liquid Effluents by Product
(mg/L of Effluent)

	15MPa Ready Mixed	20MPa Ready Mixed	30MPa Ready Mixed	60MPa Ready Mixed	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Suspended Solids	44.8971	47.1302	52.8521	53.8484	45.6229	60.9127	59.1939	59.1939
Aluminum	0.1746	0.1877	0.2218	0.2281	0.1927	0.2703	0.2676	0.2676
Phenolics	0.0027	0.0029	0.0034	0.0035	0.0029	0.0041	0.0041	0.0041
Oil & Grease	1.5240	1.5258	1.5218	1.5157	1.3354	1.5098	1.4054	1.4054
Nitrate, Nitrite	0.6281	0.6751	0.7978	0.8206	0.6927	0.9724	0.9626	0.9626
DOC	1.3328	1.4326	1.6931	1.7414	1.4701	2.0634	2.0427	2.0427
Chlorides	212.3451	228.2461	269.7378	277.4332	234.4127	328.7447	325.4412	325.4412
Sulphates	72.6212	78.0593	92.2493	94.8811	80.0686	112.4295	111.2997	111.2997
Sulphides	0.0066	0.0071	0.0084	0.0087	0.0073	0.0103	0.0102	0.0102
Ammonia, -um	0.2148	0.2309	0.2728	0.2806	0.2372	0.3325	0.3292	0.3292
Phosphorus	0.0014	0.0015	0.0018	0.0018	0.0015	0.0021	0.0021	0.0021
pH	8.05	8.07	8.11	8.11	8.07	8.16	8.15	8.15

Table 14.6
Weighted Average Liquid Effluents by Product
(g/unit of product)

	15MPa Ready Mixed per m3	20MPa Ready Mixed per m3	30MPa Ready Mixed per m3	60MPa Ready Mixed per m3	Concrete Block per block	Cement Mortar per m3	Double T Beam per m	Hollow Deck per m
Suspended Solids	49.1801	54.8191	76.1185	83.2025	0.4313	69.2734	33.2131	19.0162
Aluminum	0.1912	0.2183	0.3194	0.3524	0.0018	0.3074	0.1501	0.0860
Phenolics	0.0029	0.0033	0.0049	0.0054	0.0000	0.0047	0.0023	0.0013
Oil & Grease	1.6694	1.7747	2.1917	2.3419	0.0126	1.7170	0.7886	0.4515
Nitrate, Nitrite	0.6880	0.7853	1.1491	1.2679	0.0065	1.1058	0.5401	0.3092
DOC	1.4600	1.6663	2.4384	2.6906	0.0139	2.3466	1.1461	0.6562
Chlorides	232.6017	265.4826	388.4814	428.6691	2.2162	373.8677	182.6016	104.5490
Sulphates	79.5489	90.7941	132.8592	146.6033	0.7570	127.8614	62.4491	35.7554
Sulphides	0.0073	0.0083	0.0122	0.0134	0.0001	0.0117	0.0057	0.0033
Ammonia, -um	0.2353	0.2685	0.3929	0.4336	0.0022	0.3781	0.1847	0.1057
Phosphorus	0.0015	0.0017	0.0025	0.0028	0.0000	0.0024	0.0012	0.0007

Table 15.1
Solid Wastes due to the Production of Cement
(per unit of concrete product by city)

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
15 MPa Ready Miixed [kg/m3]	3.02	1.42	1.42	1.57	2.99	3.13
20 MPa Ready Miixed [kg/m3]	3.44	1.63	1.63	1.79	3.41	3.57
30 MPa Ready Miixed [kg/m3]	5.04	2.38	2.38	2.62	4.99	5.23
60 MPa Ready Miixed [kg/m3]	5.56	2.63	2.63	2.89	5.51	5.77
Concrete Block [kg/block]	0.0287	0.0136	0.0136	0.0149	0.0284	0.0298
Cement Mortar [kg/m3]	4.85	2.29	2.29	2.52	4.80	5.03
Double T Beam [kg/m, 10' width]	2.367	1.118	1.118	1.232	2.345	2.458
Hollow Deck [kg/m, 4'w, 8"t]	1.355	0.640	0.640	0.706	1.343	1.407

Table 15.2
Solid Wastes due to Concrete Products Manufacturing

Concrete Material	Solid Wastes
15 MPa Ready Mixed	48.13 [kg/m3]
20 MPa Ready Mixed	48.46 [kg/m3]
30 MPa Ready Mixed	48.35 [kg/m3]
60 MPa Ready Mixed	49.01 [kg/m3]
Concrete Block	0.025 [kg/block]
Cement Mortar	2.59 [kg/m3]
Double T Beam	0.769 [kg/m, 10' width]
Hollow Deck	0.440 [kg/m, 4'w, 8"t]

Table 15.3
Estimated Total Solid Waste due to Concrete Production
(by Product and City)

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
15 MPa Ready Miixed [kg/m3]	51.15	49.55	49.55	49.70	51.12	51.26
20 MPa Ready Miixed [kg/m3]	51.90	50.08	50.08	50.25	51.87	52.03
30 MPa Ready Miixed [kg/m3]	53.39	50.73	50.73	50.97	53.34	53.58
60 MPa Ready Miixed [kg/m3]	54.57	51.64	51.64	51.90	54.52	54.78
Concrete Block [kg/block]	0.0536	0.0385	0.0385	0.0398	0.0533	0.0547
Cement Mortar [kg/m3]	7.44	4.88	4.88	5.11	7.39	7.62
Double T Beam [kg/m, 10' width]	3.136	1.887	1.887	2.001	3.114	3.227
Hollow Deck [kg/m, 4'w, 8"t]	1.796	1.081	1.081	1.146	1.783	1.848

the ATHENA™
Sustainable Materials Institute

RAW MATERIAL BALANCES, ENERGY PROFILES AND ENVIRONMENTAL UNIT FACTOR ESTIMATES:

CEMENT AND STRUCTURAL CONCRETE PRODUCTS

Prepared by:

CANADA CENTRE FOR MINERAL & ENERGY TECHNOLOGY
AND
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Ottawa, Canada
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Preface

This report was originally published as part of the ATHENA™ project, initiated in 1990 by Forintek Canada Corp. with the support of Natural Resources Canada, under the name *Building Materials in the Context of Sustainable Development*. Work on the ATHENA™ project is now being carried forward by the ATHENA™ Sustainable Materials Institute, a not-for-profit organization dedicated to helping the building community meet the environmental challenges of the future.

The ultimate goal is to foster sustainable development by encouraging selection of the material mix that will minimize a building's life cycle environmental impact. To achieve that goal, the Institute is developing ATHENA™, a systems model for assessing the relative life cycle environmental implications of alternative building or assembly designs. Intended for use by building designers, researchers and policy analysts, ATHENA™ is a decision support tool which complements and augments other decision support tools like costing models. It provides a wealth of information to help users understand the environmental implications of different materials mixes or other design changes in all or part of a building.

From the outset, the project brought to bear the combined talents of architects, economists, engineers and environmentalists in a research alliance which included the following university programs, government agencies and private firms, many of which continue to contribute to the Institute as advisory members or researchers:

- CANMET, a division of Natural Resources Canada;
- Environmental Policy Research, Trent University;
- Environmental Research Group, University of British Columbia School of Architecture;
- Forintek Canada Corp.;
- JKM Associates;
- Steltech Ltd. (formerly a subsidiary of Stelco, now part of Hatch Associates);
- The Centre for Studies in Construction, University of Western Ontario;
- Venta, Glaser & Associates; and
- Wayne B. Trusty & Associates Limited.

The ATHENA™ Institute is continuing the practice of publishing all individual research reports and major progress reports to make the process as transparent as possible and to ensure the research and results are fully accessible. To ensure continuity, previously published reports such as this one are being reissued as part of the Institute series.

Institute studies and publications fall into two general categories: investigative or exploratory studies intended to further general understanding of life cycle assessment as it applies to building materials and buildings; and individual life cycle inventory studies which deal with specific industries, product groups or building life cycle stages. All studies in this latter category are firmly grounded on the principles and practices of life cycle assessment (LCA), and follow our published Research Guidelines, which define boundary or scope conditions and ensure equal treatment of all building materials and products in terms of assumptions, research decisions, estimating methods and other aspects of the work. The integration of all inventory data is a primary function of ATHENA™ itself. ATHENA™ also generates various composite measures that can best be described as environmental impact indicators, a step toward the ultimate LCA goal of developing true measures of impacts on human and ecosystem health.

We believe this report and others in the series will be of value to people concerned with the environmental implications and sustainability of our built environment. But we caution that individual industry life cycle study reports may not be entirely stand-alone documents in the sense that they tell the whole story about an individual set of products. For example, the report on concrete notes how much steel is used for reinforcing various products, but the life cycle inventory data for those steel products is included in the reports dealing with integrated and mini-mill steel production. There are also transportation and energy production and distribution aspects that are common to many different building products and are therefore handled separately within ATHENA™.

Please contact us at the address shown on the page following the cover for more information about the ATHENA™ Sustainable Materials Institute or other reports in the series.

ACKNOWLEDGMENTS

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BUILDING MATERIALS IN THE CONTEXT
OF SUSTAINABLE DEVELOPMENT
CEMENT AND CONCRETE PRODUCTS

1.0 INTRODUCTION

As part of the research alliance assembled to undertake the sustainable building materials project described in the Preface, CANMET took responsibility for developing quantitative environmental impact estimates related to the cement and concrete industries. This report explains how the impact estimates were developed and presents the results.

From CANMET's perspective, the required input for the systems model is a set of impact estimates per unit of product, called unit factors. The unit factors are defined in terms of raw materials, energy inputs, atmospheric emissions, liquid effluents, solid wastes and water usage associated with resource extraction and product manufacturing, including the transportation of raw materials at different stages of the total production process.

CANMET retained the services of Radian Canada Inc. to assist in developing overview profiles of the cement and concrete industries as a whole as well as the unit factor estimates.

1.1 RESEARCH GUIDELINES

To ensure consistent and compatible approaches by the different alliance members, all estimates had to be prepared in accordance with a set of research guidelines first issued in October 1992 and subsequently revised as work proceeded. This research protocol defined information requirements and procedures for the study, such as the following:

- the specific building products;
- the content of general and detailed industry descriptions;
- the specific energy forms, emissions and effluents of potential interest;
- the treatment of secondary building components and assemblies;
- preferred data types and sources (e.g. actual industry data and data from process studies);
- the analysis scope, including system boundaries and limits and the level of detail of the analysis;
- geographic divisions;
- transportation factors to be included when estimating transportation energy use; and
- a set of standard conventions for dealing with such aspects as non-domestic production, process feedstocks, in-plant recycling and multiple products.

In addition, the research guidelines provided a set of conversion factors and tables of standard factors for calculating energy contents and emissions by fuel type.

The analysis limits established for the project in the guidelines are similar to a Level II analysis for energy studies as determined by the International Federation of Institutes of

Advanced Studies. These limits typically capture about 90% to 95% of the full impacts of an industry.

The Research Guidelines are available under separate cover as part of the full set of project reports and we have not, in this report, duplicated that material by explaining the rationale for all steps in the research and calculation process. For example, the Research Guidelines require that empty backhauls be included when calculating transportation energy use in certain circumstances. Our calculations therefore show the addition of such backhaul mileages without explaining why backhauls should be included. However, we have provided full explanations wherever our calculations do not conform to the guidelines because of data limitations or for other reasons.

1.2 STUDY STRUCTURE

The systems model requires unit factors for the following specific concrete products:

- 15, 20 and 30 MPa ready mixed concrete;
- precast 'double T' beams with median values for steel and concrete content;
- precast hollow deck with median values for steel and concrete content;
- standard concrete blocks; and
- cement mortar.

Portland cement is an essential raw material for the production of all of the above concrete products and we had to fully analyze the portland cement industry before developing unit factors for these products. That fact dictated how our study was structured.

Unit factor estimates for the Canadian portland cement industry were developed and are expressed in terms of material inputs or waste outputs per unit of product. Similar estimates were then developed for the other materials (i.e. in addition to portland cement) required to make concrete and the two sets of factors were combined to develop the final unit factor estimates. The portland cement estimates were adjusted at this stage to reflect the relative proportion of portland cement used in the formulations of the individual concrete products.

The specific analysis procedures and calculations are described in detail in the relevant sections of this report. The key point at this stage is that the study was structured as two separate, but obviously related, analysis streams — one for portland cement and one for the concrete products of interest.

Estimates are not required in the form of final unit factors for cement and we therefore could have combined the estimates in a different manner when calculating unit factors for concrete products. However, we decided to develop full unit factor estimates for cement and to present them as such because cement is essential to the production of all concrete products. Having a complete set of unit factors for cement production will make it easier to develop unit factors for other concrete products that might be added to the product list in the future. It will also be easier to update the model to take account of any future gains in energy efficiency or pollution abatement as the portland cement industry continues to evolve in an environmentally sensitive manner.

1.3 REPORT STRUCTURE

The structure of this report basically parallels the study structure. The rest of the report is divided into two main parts: Part I, which comprises Sections 2 through 8, deals with the cement industry; Part II, which comprises Sections 9 through 16, deals with the concrete industry.

As indicated below, the basic progression in each part involves an overview section followed by a series of sections dealing with each of the environmental impact areas (e.g. raw material use, energy use, emissions, etc.) Results are presented to show regional variations and, as necessary, by production stage (e.g. resource extraction, transportation and manufacturing).

The following regional breakdown was specified in the Research Guidelines:

- West Coast (British Columbia);
- Prairie (Alberta and Saskatchewan);
- Central (Manitoba and Ontario); and
- East (Quebec and Atlantic Provinces).

Part I of the report is organized as follows:

Section 2 presents an overview profile of the portland cement industry in Canada, including a description of the different production processes, the industry structure in geographic, process and capacity terms, and the general nature of resource and energy use, emissions and other wastes.

Section 3 details raw material use by the industry on a regional basis, and discusses raw material transportation requirements.

Section 4 describes the energy use analysis and presents the results, with sub-divisions by region and by stage of production.

Section 5 deals with atmospheric emissions on a regional basis by production stage, including the analysis method and results.

Section 6 focuses on liquid effluents.

Section 7 deals with solid wastes.

Section 8 provides a summary of all of the unit factor estimates developed in the preceding six sections.

Part II of the report follows essentially the same progression as Part I. Section 9 provides an overview of the concrete products industry and Sections 10 through 16 detail the analysis and results, by product, for each of the unit factor categories. The final section provides a summary of the results.

PART I

CEMENT PRODUCTION

PART I: CEMENT PRODUCTION

2.0 THE PORTLAND CEMENT INDUSTRY: AN OVERVIEW

This section provides an overview of the Canadian portland cement industry, starting with a description of the basic manufacturing processes. Related energy use and efficiency issues and waste outputs are also discussed as a prelude to the more detailed examination of these aspects of industry operations in subsequent sections. Here the emphasis is on how the industry has improved its operations in the past and on the opportunities for future improvements, while later sections focus on current performance in typical plants. The final subsection details the current industry structure.

2.1 CEMENT MANUFACTURING

Portland cement is manufactured by first heating a mixture of limestone and shale or clay (or other materials of similar composition) with additives such as sand, iron ore and bauxite used as correctives to ensure an appropriate raw materials mixture, to produce nodules of clinker. The clinker is then mixed with about 3% to 6% gypsum and finely ground to make finished cement. About 1.60 tonnes of raw material are required to make 1 tonne of finished cement. The basic manufacturing steps are depicted in Figure 2.1 and summarized below.

1. Limestone and shale is quarried, generally by drilling and blasting, moved to a conventional crusher close to the quarry site, crushed and mixed to ensure a reasonably homogeneous blend which is then transported to the main plant site.

3. At the plant, the quarried materials are preblended with sand, iron ore, bauxite or other purchased additives. This step is usually done with an automatic preblending system, with frequent chemical analyses of the raw materials to ensure the correct chemical composition of the raw materials mixture. On-line analyzers permit instantaneous determination of chemical composition and frequent adjustments can be made to the rate of feed of the various components to obtain a correct and uniform composition. A uniform feed leads to a steady kiln operation, which has a beneficial effect on fuel consumption.

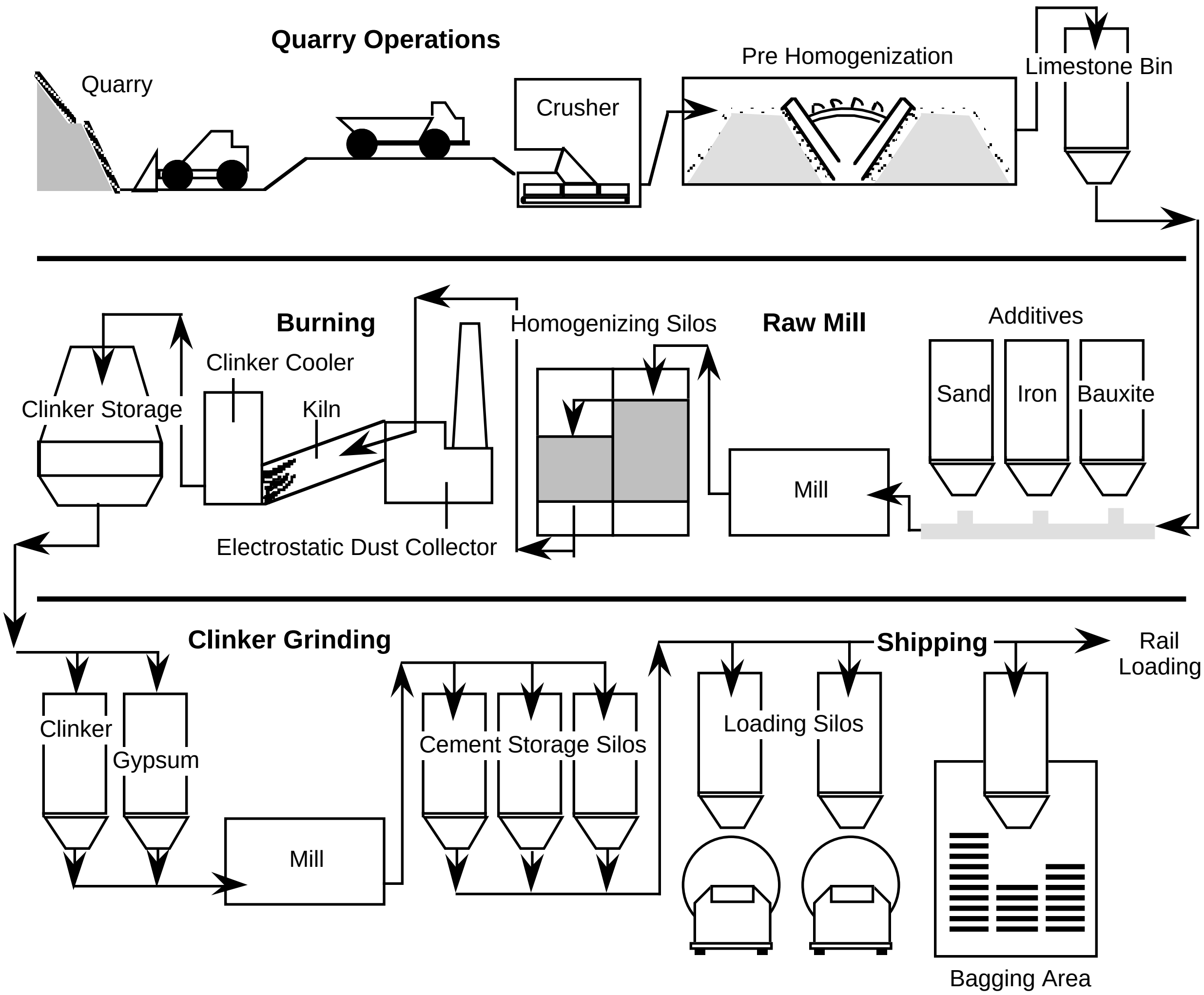
4. The properly proportioned raw materials are then fed into one or more mills for raw grinding. At this point, one of two main types of processes can be followed:

    a) a dry process where only dry raw materials enter the grinding mill and the mill product is a fine powder called raw meal; or
    b) a wet process where water is mixed with the raw materials entering the mill in a proportion of about 30% water and the mill product is a slurry.

5. After grinding, the raw meal or slurry is blended. Raw meal is fed into silos where compressed air blends and homogenizes the meal. In the wet process, the slurry is stored in concrete or steel tanks where paddles or propellers keep the slurry in motion, with compressed air insufflated to further promote homogenization.

6. The next, and most energy intensive step, is pyroprocessing. The raw meal or slurry is fed to a rotary kiln where it is heated to a temperature of about 1450 degrees Celsius to convert the meal or slurry into clinker.

Figure 2.1
THE CEMENT MANUFACTURING PROCESS



Source: Adapted from *The Cement Industries Contribution to Canada's Green Plan* (Canadian Portland Cement Association, June 1991), p. 3.

In the wet process — the least energy efficient process — kilns have a drying section inside the kiln, consisting of chain curtains. As the kiln rotates, the chains are constantly coated with slurry which is exposed to hot gases passing through the chain section causing the water to evaporate. The big disadvantage of wet kilns is the high heat required to evaporate the approximately 30% water content of the slurry. The installation of a slurry filter press ahead of the kiln helps by reducing the water content of the slurry to about 14%. However, additional electric power and maintenance of the filter cloth adds significant cost to the process.

The dry process represents a significant improvement over the wet process in terms of energy efficiency. But fuel consumption in original long dry process kilns is still high because considerable heat is wasted when high temperature exhaust gases leave the kiln. To help overcome that disadvantage, efficient suspension preheaters were developed in the early 1950's . In principle, the meal is introduced into the top of the preheater and descends in a counterflow to the hot kiln exhaust gas so that the meal is heated and enters the kiln at a high temperature, resulting in a significant reduction in heat consumption.

Another development introduced in the 1970's is the precalciner, which is basically a fuel burner located in the lower part of the preheater to further preheat the meal before it enters the kiln.

7. An integral part of the clinker production system is the clinker cooler in which the red-hot clinker is air cooled as it is discharged from the kiln. Part or all of the hot air leaving the cooler is used as secondary combustion air for the kiln burner.

8. Dust collectors are needed for removing the dust from the kiln exhaust gas and from the clinker cooler exhaust gas. Two types of dust collectors are used:

   a) precipitators in which the dust particles are separated from the gas stream by electrostatic action; and
   b) bagfilters in which the dust is filtered out through bags.

   Although both types of dust collectors are efficient, the tendency is more towards the use of bagfilters to meet modern emission standards. Unfortunately, fan power consumption in a bagfilter is much higher than in an electrostatic precipitator because of the higher gas flow resistance.

9. Cement clinker, together with 3 to 6% gypsum is fed to ball mills where it is ground to the required fineness to yield portland cement.

   Grinding by conventional ball mills is an energy intensive operation and the cement industry has therefore devoted considerable effort to introducing improved technology such as high efficiency classifiers and roller presses. Improvements in grinding aids, grinding media, mill liners and the use of more complex grinding circuits have also resulted in small but significant energy efficiency gains.[1]

   A recent development is high efficiency separators. In these classifiers, the airstream in the separation zone is horizontal rather than vertical which results in a longer residence time of the material in the separating zone, a consequent sharper separation of fine and coarse particles and less overgrinding. Replacing a conventional separator by a high efficiency separator leads to increases in mill output of about 15% and reductions in specific power use of about 8%.[2]

10. The final cement product is usually stored in storage silos which then provide the feed for loading or bagging silos. For bag shipments, the cement is fed from the silos to packing machines and into paper bags of 40 kg each. Onward transportation could be by road, rail or water.

Usually a plant produces various types of cement that differ in terms of final strength, resistance to chemical attack, time of setting and strength development and workability. The different types of cement are produced by changing the raw meal composition, grinding the clinker to different degrees of fineness or feeding the finish grinding mill with additional materials such as slag, fly ash or silica fume.

2.1.1 Energy Use and Efficiency

Cement manufacturing is a relatively energy intensive process, although the energy embodied in final concrete products is low compared to many other building products because so little cement is needed to make concrete (see Section 9.0).

About 88% of the energy used in a cement plant is fuel to fire the kilns, with most of the remainder in the form of electrical energy for motors to drive grinding mills, rotate the kiln and transfer materials, and for electrical devices to clean exhaust gases. Since the energy crisis of the 1970's the use of oil as a kiln fuel declined from about 40% of total kiln fuels to about 4% in 1989, while the use of coal or coke increased from 11% to 70% over the same period. Of this total, petroleum coke accounted for about 17% of kiln fuel in 1989. Natural gas accounted for the remaining 25% of kiln fuel in 1989.[3]

The Canadian portland cement industry has the ability to replace about 50% of the fossil fuels currently used with waste materials such as municipal garbage, scrap tires, spent solvents or used oils. On the basis of stack emission testing, the industry believes all of these kinds of waste materials could be safely burned in cement kilns with gains for both the industry and society.[4] In Canada, abut 2% of the fuel used by the cement industry in 1991 was derived from wastes, compared to about 8% in the United States. Since 1991 several additional permits have been obtained to burn wastes, but the use of wastes, particularly hazardous wastes, is still hampered by regulatory agencies.

As noted in the process description (point 6, above), the shift from the wet process to long dry kilns and to dry kilns with preheaters has resulted in significant energy conservation by the cement industry. Dry plants with preheaters and/or precalciners use about 3.6 giga joules of energy per tonne of clinker compared to about 4.5 GJ/t for long dry plants and about 6.0 GJ/t for wet process plants.

However, the opportunity for further gains through this route has nearly been exhausted: by 1991, 90% of Canadian cement production was from dry process plants. Some of the remaining wet kilns are effectively used for specialty products and low alkali cements or are only used during peak demand periods.[5]

Other possibilities for improving pyroprocessing are being studied, including fluidized bed kilns and the development of low tricalcium silicate (C_3S) cements. However, low C_3S cements have slow setting times and low early concrete strength and research is still needed to find ways to counteract these undesirable characteristics.[6]

On the electrical side, energy saving steps already mentioned in the preceding subsection include high efficiency classifiers and separators and roller presses. Other steps incorporated to varying degrees in Canadian mills include variable speed fan drives, mechanical conveyors, high efficiency motors and central process controls.

2.1.2 Atmospheric Emissions

The critical atmospheric emissions from cement plants are carbon dioxide (CO_2), nitrous oxides (NO_x), sulphur oxides (SO_x) and particulates.

The major source of emissions is the kiln operation which predominantly releases nitrogen, CO_2, water vapour and particulates as well as a variety of minor substances typical of most combustion processes. A major difference between cement kilns and other types of combustion processes is the source of CO_2 emissions. In a cement kiln about 50% of the CO_2 is the result of fuel combustion, while the remaining 50% is from decarbonization of the limestone.[7]

The levels of NO_x and SO_x emissions, as well as the levels of CO_2 from combustion, are largely a function of the fuel used to fire a cement kiln. For example, CO_2 and SO_x emissions are higher when a kiln is fired with coal than when using natural gas, but NO_x emissions are lower. It is worth noting, however, that cement kilns can burn high sulphur coals with lower sulphur dioxide (SO_2) emissions than any other industry because of the scrubbing action of the raw materials which absorb sulphur during the process and incorporate it into the final product. An electric utility has to desulphurize flue gases in order to achieve the same levels of SO_2 emissions as a cement kiln using the same quality coal.

Atmospheric emissions from cement plants can be reduced by burning less fuel and the industry has already made substantial gains in that direction as discussed in the preceding subsection. The relative proportions of specific emissions can also be altered by changing the fuels used as noted above, but there are economic and practical limits to that approach depending on the part of country in which a plant is located. For example, natural gas is not available in the Atlantic provinces and coal is both abundant and relatively inexpensive. In contrast, natural gas is the principal fuel used in western Canada.

Other opportunities to reduce non-particulate emissions depend on the emission being considered and generally have to be evaluated on a specific plant-by-plant basis. For example, it may be possible to reduce CO_2 emissions by using lime wastes to replace some limestone, thereby lowering CO_2 generation from decarbonization as well as from fuel combustion. Low C_3S cements are another possibility if research results in improved performance of these cements. In the case of NO_x emissions, it may be possible to install low NO_x burners in kilns and to introduce ammonia into the kiln to convert NO_x to water and nitrogen. Any further reduction in SO_x emissions would require a switch to low sulphur fuels, the use of wastes as fuel or the installation of expensive stack scrubbers which significantly increase fuel consumption.

Particulate emissions have long been a concern of the industry because of the nature of the raw materials and processes. Quarrying, blasting, crushing, raw material transportation, raw material stockpiles and clinker and finished cement storage are all potential sources of fugitive dust that has to be controlled to the extent practical. The industry has responded by installing wind breaks, stockpile covers, shrouds and indoor clinker storage as well as by following sound management and housekeeping practices.

Particulate emissions from kilns are more difficult to control because of the unique nature of the emissions in the cement industry. Unlike most industries, particulates from a cement kiln do not consist only of fuel residues from combustion. The fine portion of the ground raw material feed to the kiln is also a potential source of particulate emissions. Electrostatic precipitators and bagfilters are used to capture particulate emissions to the extent possible. But submicron fractions of the raw material pass through the collectors giving rise to particulate emission levels that are within Canadian standards.[8]

The best way to deal with collected dust from an environmental perspective is to return it to the process and this is the way a major portion of the collected dust is handled. However, recycling is difficult because the dust contains uncalcined raw materials as well as smaller amounts of partially calcined material and cement clinker and, in the case of some plants, the chemistry of the raw materials precludes recycling all of this dust. Plants that produce low alkali cements have further limitations on their ability to recycle kiln dust because it first has to be treated to reduce its alkalinity.

2.1.3 Solid Wastes

Residual kiln dust that cannot be recycled is a solid waste that is either treated as a by-product and sold or is disposed of by land-filling on site. In the latter situation, the land fill operation has to be carefully managed because the dust may contain low levels of metals and compounds that could adversely affect groundwater. Care also has to be taken to ensure the kiln dust is not wind blown.

The industry has done considerable research to identify markets for residual kiln dust and some is now used for fertilizers, for the treatment of municipal sewage, as soil sweeteners and as a stabilizing agent for soils and sludge. In the United States, work is under way to develop cement kiln dust and flue gas scrubbing technology that may make it possible to fully re-use kiln dust as raw kiln feed. The technology could also result in reductions in SO_2 and NO_x emissions in flue gases as well as yielding operational savings, including the production of marketable potassium sulphate.[9]

Another potential source of solid waste at cement plants is spent refractory brick used to line kilns. Some plants use a brick that contains chromium and, if it cannot be crushed and mixed with the raw feed for incorporation into clinker, the brick has to be disposed of in an environmentally acceptable manner.

2.2 CURRENT INDUSTRY STRUCTURE

In 1991, nine companies operated a total of 32 cement kilns at 18 plants located across Canada. The companies, plant locations and kiln capacities by basic process types (i.e. wet, long dry, dry with preheater or dry with precalciner) are shown in Table 2.1. The table also shows the kilns with roller mills, high efficiency separators and roller presses.

Total 1991 clinker production capacity (i.e. kiln capacity) in Canada was 14.823 million tonnes, with the combined capacity of long dry, dry with preheater and dry with precalciner kilns accounting for about 83% of that total. However, as noted in Subsection 2.1.1, that figure was about 90% in 1991 on an actual production as opposed to capacity basis because some wet kilns only operate during peak demand periods.

Table 2.1
1991 CANADIAN CEMENT PLANT LOCATIONS, KILN TYPES, KILN CAPACITIES AND OTHER EQUIPMENT

	Kilns (1,000 t/y)					High	
Company and Location	**Wet**	**Long Dry**	**Pre-heater**	**Pre-calciner**	**Roller Mills**	**Efficiency Separators**	**Roller Presses**
Tilbury Cement Ltd.			1087		1	2	
Delta, BC							
Lafarge Canada Inc.	220					2	
Richmond, BC	255						
Lafarge Canada Inc.		195					
Kamloops, BC							
Lafarge Canada Inc.		381					
Exshaw, AB				650			
Inland Cement Ltd.				727	1		
Edmonton, AB							
St. Mary's Cement Co.			646		1		1
St. Mary, ON							
Federal White Cement		151				1	1
Woodstock, ON							
Lafarge Canada Inc.	274						
Woodstock, ON	291						
St. Lawrence Cement Inc.	280					1	
Mississauga, ON	280						
				1320			
St. Mary's Cement Co.				1503	1	1	
Bowmanville, ON							
Lake Ontario Cement		291			2		
Picton, ON			835				
Lafarge Canada Inc.			1047			2	
Bath, ON							
Lafarge Canada Inc.		496					
St. Constant, PQ		497					
St. Lawrence Cement Inc.		260				1	
Joliette, PQ		260					
		260					
		260					
St. Lawrence Cement Inc.	305					2	
Quebec City, PQ	307						
Climent Quebec Inc.	168				1		1
St. Basile, PQ	168						
				740			
Lafarge Canada Inc.		235					
Brookfield, NS		281					
North Star Cement Ltd.			153			1	
Corner Brook, NF							
Capacity Totals	**2,548**	**3,567**	**3,768**	**4,940**			

Sources: 1) Canadian Portland Cement Association, *Canadian Plant Information Summary - 1991*, August 1992
2) Holderbank Consulting Ltd., *Present and Future Use of Energy in the Cement and Concrete Industries in Canada*, prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993.

On a regional basis, about 47% of the 1991 clinker capacity was in Ontario, 24% was split almost equally between Alberta and British Columbia, 25% was in Quebec, and the remaining 4% was in the Atlantic provinces.

There are also some plants in Canada that do not produce clinker but do have finish grinding facilities to produce cement using clinker from other plants. Those plants are not included here because our focus is on the fully integrated plants that carry out all manufacturing functions from raw resource extraction to the production of cement.

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[1] *The Cement Industry's Contribution to Canada's Green Plan* (Canadian Portland Cement Association, 1991).

[2] *Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, December 1992 draft).

[3] Canadian Portland Cement Association, op. cit.

[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] Ibid.

[8] Ibid.

[9] Ibid.

3.0 RAW MATERIAL REQUIREMENTS AND TRANSPORTATION

This section provides a brief overview of raw material requirements for cement production in Canada on a regional basis. The section also provides an overview of transportation distances and typical modes used to move raw materials to the cement plants, again on a regional basis. Transportation data underlying the overview was used to develop corresponding energy estimates presented in Section 4.0.

Data on actual raw material requirements, transportation distances and modes was provided to Radian by plants in 16 of the 18 locations listed in Table 2.1 (preceding section). However, we are treating the individual plant data as confidential and all data presented in this report is therefore shown as averages, typically weighted averages on either a regional or process basis.

For the one Ontario plant that did not provide detailed raw material and transportation data, we assumed the cement composition would be similar to that for a nearby plant and that transportation distances and modes would also be similar. For the one Quebec plant that did not provide this data, we assumed the same numbers as the weighted average for the rest of the East region.

The weights used to develop these and other estimates presented in later sections are the kiln capacities shown in Table 2.1.[1] Where relevant (e.g. in developing manufacturing energy use estimates) a distinction was made between kilns at the same plant using different processes (i.e. a plant with two kilns using two different processes was essentially treated as two plants for the purpose of developing weighted averages).

3.1 RAW MATERIAL REQUIREMENTS

Clinker typically is composed of about 67% calcium carbonate ($CaCO_3$), 22% silicon oxide (SiO_2), 5% aluminum oxide (Al_2O_3), 3% iron oxide (Fe_2O_3) and 3% of other components.[2] Limestone is the main source of calcium carbonate and clay or shale provide aluminum silicates. All of these materials also contain iron oxides. The clinker is mixed with a relatively small amount of gypsum, and possibly with up to 5% limestone, and then finely ground to make finished cement, with gypsum controlling the rate of set.

When expressed as percentages of calcium, silicon, aluminum and iron oxides, all cement formulations are essentially the same irrespective of the manufacturing process used or the location of the plant. However, limestone, clay and shale occur in nature in wide variety with a range of compositions. Differences in the composition of locally available limestone, clay and shale result in differences in the mixture of these materials used by specific plants and in requirements to adjust the mixture with other additives. Additional materials like mill scale, iron slag or iron ore residue may be used in small amounts to adjust formulations to achieve the desired content. Similarly, bauxite or even aluminum scrap may be added to adjust Al_2O_3 levels, and sand is often used as a supplementary source of silica. In some operations, sand replaces clay or shale. Industrial by-products like fly ash and blast furnace slag have also been increasingly used as raw materials in Canadian cement production over the last few years.

Table 3.1 provides a breakdown of the estimated weighted average raw material use in Canadian cement production by region, assuming 1.60 tonnes of raw material per tonne of clinker.

Table 3.1
WEIGHTED AVERAGE RAW MATERIAL USE BY REGION
(per tonne of finished cement)

RAW MATERIALS	REGION									
	W. Coast		Prairie		Central		Eastern		Canada	
	%	tonnes	%	tonnes	%	tonnes	%	tonnes	%	tonnes
Limestone	69.32	1.17	78.92	1.33	86.06	1.45	78.82	1.31	81.09	1.36
Clay/Shale	19.13	0.32	13.89	0.23	3.85	0.06	10.91	0.18	8.94	0.15
Iron	1.67	0.03	2.17	0.04	2.13	0.04	0.48	0.01	1.59	0.03
Sand	3.99	0.07	0.00	0.00	1.47	0.02	5.49	0.09	2.78	0.05
Ash	0.39	0.01	0.00	0.00	1.74	0.03	0.00	0.00	0.86	0.01
Other	0.17	0.003	0.00	0.00	0.00	0.00	0.70	0.01	0.23	0.004
Gypsum	5.33	0.09	5.00	0.08	4.75	0.08	3.60	0.06	4.51	0.08
Total	100.00	1.69	99.99	1.68	100.00	1.68	100.00	1.66	100.00	1.68

In the West Coast region, limestone accounts for less than 70% of the raw material mixture, for about 79% in the Prairie and Eastern regions and for about 86% in the Central region. The national weighted average composition includes about 81% limestone. West Coast plants correspondingly use more than twice the weighted average of clay or shale compared to plants in the rest of Canada, while Central region plants use less of these materials because limestone in that region evidently contains rather high amounts of silicates and aluminates compared to the rest of the country.

There appears to be less difference in raw material compositions when plants are examined on a process rather than regional basis as in Table 3.2.

Table 3.2
WEIGHTED AVERAGE RAW MATERIAL USE BY PROCESS
(%)

RAW MATERIALS	PROCESS			
	Dry Long	Wet	Precalciner	Preheater
Limestone	81.89	82.83	84.54	74.62
Clay/Shale	7.01	7.38	7.44	14.22
Iron	1.14	1.51	2.03	1.37
Sand	5.53	1.76	0.69	2.93
Ash	0.59	2.11	0.00	1.39
Other	0.22	0.43	0.30	0.00
Gypsum	3.33	3.96	5.00	5.34
Total	99.71	99.98	100.01	99.86

The formulations are essentially the same for the dry long, wet and dry precalciner processes. Only the dry preheater process appears to be different, but this apparent difference is actually due to the location of plants using this process rather than to differences in the process itself.

3.2 RAW MATERIAL TRANSPORTATION

We cannot so easily provide summary tables of the raw transportation data because of the wide variability in that data: distances and modes vary by individual raw material as well as by plant. Because of the variability, the weighted averages for transportation were calculated in energy terms only (i.e. after first converting the transportation data into energy use by type of fuel for each plant). The weighted average transportation energy estimates are shown in the next section with other energy data and the rest of this sub-section simply provides an overview of raw material transportation in the various regions as a prelude to those estimates.

In the West Coast region, the two coastal plants use ship transportation to move most of their raw materials, sometimes over quite long distances. For example, gypsum for these plants is shipped from Baja California. Limestone also moves by ship, but over a much shorter distance. The interior plant is more typical of plants in the Prairie and Central regions, with limestone moved by conveyor from a nearby quarry and most other materials sourced within economic trucking distance. A limited amount of rail transportation is also used by that plant.

As might be expected, the Prairie region plants primarily use rail and truck to move raw materials, with the exception of the limestone supply to one of the plants which is moved by conveyor. Overall, rail is the more dominant mode for one of the plants and truck for the other.

In the Central Region, most plants are situated near limestone quarries and conveyors are used to move the limestone as well as the limited amounts of clay or shale required in this region (see Table 3.1). It seems every effort is made to move other raw materials by ship on the Great Lakes and St. Lawrence River. For example, it apparently makes economic sense for most plants to move gypsum by ship from Nova Scotia rather than by truck from more local sources, although the relative quality of the gypsum could also affect the decision. Those materials not moved by conveyor or ship are trucked in all but one instance (where rail is used), with the distances ranging from a few kilometres to several hundred.

Most raw materials used by the East region plants are available locally and are moved by conveyor or truck with the exception of the gypsum supply to the Quebec plants which moves by ship from Nova Scotia. Rail transportation is not used in this region.

The favourable location of the East region plants relative to raw material supplies makes this the most efficient region in terms of raw material transportation energy use, as will be seen in the next section. However, their location relative to cement markets makes the East region the least energy efficient in terms of the transportation of finished cement (discussed in Section 4.0).

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[1]The weighting process simply involved multiplying the measure of interest for a specific plant (e.g. raw material or energy use) by the percentage of total kiln capacity (e.g. within a region) accounted for by that plant and summing the results.
[2]H. F. W. Taylor, *Cement Chemistry* (London: Academic Press Ltd., Harcourt Brace Jovanovitch, 1992).

4.0 ENERGY USE

In this section, we explain and present the estimates of energy use developed for the raw material extraction and transportation, cement manufacturing and finished cement transportation stages of the cement production process. All of the results are presented and discussed in terms of weighted regional averages using the plant kiln capacities as weights. Various tables show total energy use by region and process stage and we also show the breakdown by energy type because that information is directly relevant to the estimation of atmospheric emissions in a subsequent section of the report.

In the section dealing with manufacturing energy, we have included a comparative table to illustrate how the estimates developed for this study compare to those developed by others for that process stage. In the final summary section, we have also included a table showing total manufacturing stage energy use on a national weighted average basis by process type to underscore the differences in the processes and the gains made by adopting more energy efficient processes.

4.1 RAW MATERIAL EXTRACTION AND TRANSPORTATION

As noted in Section 2.1, the main raw materials, including gypsum, are typically quarried and crushed before transportation to the main cement plant. However, our estimates of extraction energy relate solely to the quarrying part of the operation, with all primary and secondary crushing operations and associated energy use included in the manufacturing stage of production (Section 4.2). This approach somewhat distorts the break-down of energy use estimates by stage of production but it does not understate energy use. In any event, the approach is unavoidable because of the lack of sufficient detailed information about the extraction processes and equipment locations on a plant-by-plant basis.

It is also worth noting that the above approach is almost immaterial in the case of the many plants located close to the limestone quarry because limestone and clay or shale account for the bulk of the raw materials and are moved to the plant by conveyor. In those cases, there is little distinction between saying the primary crushing operation is at the quarry or at the plant.

This approach does create some distortions in terms of the atmospheric emission estimates associated with electricity use, the energy form used for crushing and grinding operations. The estimates of electricity use developed in this report will be translated in the Sustainable Materials Project calculation model into the mixture of primary energy forms used to generate the electricity at the relevant generating facilities and emission factors will be calculated on that basis. To make this adjustment, the model assumes electricity comes from the relevant regional electrical grid. Therefore, when we assume gypsum from Nova Scotia is crushed in Ontario the model will assign those electricity estimates to the Ontario grid and will estimate emissions accordingly. The estimates will likely be different from those that would be made assuming use of electricity from the Nova Scotia grid. Again, the lack of data precludes our doing anything to avoid this problem and we believe it will in any case be relatively minor in terms of the overall atmospheric emission estimates for cement production.

To estimate energy use in quarrying, we have assumed all energy use is in the form of diesel fuel (road) as specified in the Sustainable Materials Project Research Guidelines (Section 4.6, p. 17). We have also assumed all materials are extracted from open pit mining and that it takes 0.027 gigajoules (GJ) to extract one tonne of raw material.[1]

The above assumptions are reasonable in the case of limestone, clay, shale and gypsum. But it is not reasonable to assume open pit mining in the case of some of the additives such as mill scale, fly ash and iron slag. Energy is obviously required to produce or process some additives, but we have no data to indicate the amount or type of energy involved. We have therefore applied the above quarrying factor to these materials to ensure the associated energy requirements are not ignored. This approach undoubtedly distorts the results, but the extent of the distortion will be minor because not all plants use such materials and when they do the amounts are relatively small as indicated in Table 3.1. In addition, there are probably compensating errors, with understatement of the energy use in the case of some materials for some plants and overstatement in the case of other materials and plants.

The estimates of raw material extraction and transportation energy use are shown in Table 4.1 on a weighted average basis by region and for Canada as a whole.

Table 4.1
WEIGHTED AVERAGE ENERGY USE FOR RAW MATERIAL EXTRACTION AND TRANSPORTATION
(GJ/tonne of finished cement)

REGION	EXTRACTION	TRANSPORTATION				
	Diesel - Road	Diesel - Road	Diesel - Rail	HFO - Marine	Electricity	Total Trans.
West Coast	0.04464	0.00736	0.00055	0.08201	0.00048	0.09041
Prairie	0.04455	0.03618	0.18846	0.00	0.00077	0.22543
Central	0.04451	0.02905	0.00556	0.03163	0.00203	0.06829
East	0.04417	0.01455	0.00	0.00794	0.00116	0.02365
CANADA	0.04443	0.02303	0.02501	0.02684	0.00144	0.07633

Note: HFO is heavy fuel oil

The transportation energy use estimates were made by applying the following combustion energy factors from the Research Guidelines:

Mode	Fuel	Energy Consumed (MJ/tonne-kilometre)
Truck	Diesel - Road	1.18
Rail	Diesel - Rail	0.49
Ship	HFO - Marine	0.12

The above factors were applied to the individual raw material tonnages required per tonne of finished cement on a plant-by-plant basis using haul distance estimates provided by the companies. The distances were doubled for all modes except conveyors (electricity) to account for empty backhauls in accordance with the research guidelines. The weighted regional averages shown in Table 4.1 were then calculated from the individual plant estimates.

4.2 CEMENT MANUFACTURING

Only limited information regarding energy use in manufacturing was made available by the individual cement plants. We therefore relied on the Gardner model developed by Ontario Hydro and based on a software package developed by the Electric Power Research Institute to generate the estimates presented in this sub-section.[2]

After discussion with Ontario Hydro, we adopted the model with necessary corrections and expanded its application to cover all regions. Adjustments to the model included the addition of information about process types and processing equipment used in the individual plants (see Table 2.1). We also incorporated plant-specific information about fuel mixes used in pyroprocessing — the most energy intensive step in the manufacturing process.[3]

The model was applied plant-by-plant with the results used to calculate the weighted regional and national averages shown in subsequent tables. However, we had to make the following assumptions in order to generate results in the form required.

1. The Gardner model provides energy use factors per tonne of raw material handled (e.g. for crushing, grinding, pyroprocessing, etc.) while our interest is in energy use per tonne of finished cement. We therefore maintained the assumption that 1.6 tonnes of raw material are required per tonne of clinker (see Section 3.1). We further assumed that clinker accounts for 92.5% of finished cement. This latter number is not fully consistent with the estimates of clinker versus gypsum (the latter ranging between 3.60 and 5.33% of finished cement on a weighted regional average basis) shown in Table 3.1, because plants often add small amounts of raw limestone to produce finished cement with the desired properties. The 1.6 figure was used to factor crushing and grinding energy use estimates from the Gardner model, while the 0.925 figure was used to factor pyroprocessing energy use estimates. The result is that all energy use estimates are per tonne of finished cement.

2. Plants often use a secondary as well as a primary pyroprocessing fuel. We have assumed that primary fuels represent 75% and secondary fuels 25% of total pyroprocessing energy use on a plant-by-plant basis. In cases where more than one fuel was cited in either the primary or secondary category, we assumed the fuels are used in equal proportions within that category.

Table 4.2 shows the estimated weighted average energy use in cement manufacturing by process step.

Table 4.2
WEIGHTED AVERAGE ENERGY USE IN MANUFACTURING BY PROCESS STEP
(GJ/tonne of finished cement)

	PROCESS STEP					
REGION	Primary Crushing	Secondary Crushing	Raw Grinding	Pyro-processing	Finish Grinding	Total Manufacturing
West Coast	0.01786	0.03571	0.31200	4.15110	0.17223	4.68889
Prairie	0.01782	0.03564	0.33523	3.70837	0.20880	4.30586
Central	0.01780	0.03561	0.34689	3.84786	0.19740	4.44557
East	0.01767	0.03534	0.36298	4.91610	0.19464	5.52673
CANADA	0.01777	0.03554	0.34614	4.18363	0.19495	4.77804

Table 4.3 combines the process steps and shows the above total energy requirements by energy form.

Table 4.3
WEIGHTED AVERAGE ENERGY USE IN MANUFACTURING BY ENERGY FORM
(GJ/tonne of finished cement)

	ENERGY FORM						
REGION	Nat. Gas	Coal	Oil	Coke	Waste	Electricity	Total Manufacturing
West Coast	2.30281	1.46330	0.15547	0.19631	0.00 *	0.57101	4.68889
Prairie	3.66648	0.00	0.00	0.00	0.00 *	0.63939	4.30586
Central	0.58195	2.26870	0.08101	0.63060	0.26626	0.61705	4.44557
East	0.77435	1.66300	0.84800	1.18701	0.46928	0.58509	5.52673
CANADA	1.20873	1.72478	0.30738	0.66912	0.26325	0.60478	4.77804

* Since 1991, the cut-off year for most data used in this study, two plants in the west coast region and one in the prairie region have reduced their fossil fuel use in the kilns by burning scrap tires.

Table 4.4 compares the weighted national average manufacturing energy use estimates to comparable estimates prepared by Holderbank[4] and by the Canadian Portland Cement Association (CPCA).[5] The comparison is restricted to only the manufacturing stage and to the national level because the other sources have not estimated energy use for raw material extraction and transportation, nor have they developed estimates on a regional basis.

Table 4.4
WEIGHTED CANADIAN AVERAGE ENERGY USE: MANUFACTURING STAGE ONLY
(GJ/tonne of finished cement)

ORGANIZATION	ENERGY USE
Radian/CANMET (Gardner Model)	4.78
Holderbank (estimate for 1990)	4.68
CPCA (estimate for 1991)	4.55

We believe the comparative estimates confirm the validity of the Gardner model as applied here. The difference between our estimate and Holderbank is only 0.10 GJ/tonne, or 2.0%, while the difference between our estimate and CPCA is 0.23 GJ/tonne, 5.0%. The difference between us and Holderbank may be partly explained by the fact we used 1991 CPCA volume information while Holderbank used 1990 industry data.

4.3 FINISHED CEMENT TRANSPORTATION

This final energy use category covers the transportation of finished cement from plants to Canadian market distribution centres.

As in the case of raw material transportation, information about transportation distances and modes was provided by 16 of the plants. However, the information provided by the plants was in the form of overall average cement transportation distances which tend to overstate distances relative to the requirements of this study because they include transportation to U.S. export markets. An amendment to the Research Guidelines states that finished product transportation data should be provided in kilometres by mode of transport for average haul distances to Halifax, Montreal, Toronto, Winnipeg, Calgary and Vancouver from the relevant production points. The Guidelines further noted that 'relevant production points' would be the facilities typically serving each of the cities.

The guideline was intended to cover the final products used in building construction, in this case concrete. But it is also useful as a guide for estimating distances for the intermediate cement product and we have therefore assumed plants in each region serve the cities listed below. Most plants indicated the modes typically used to transport finished cement in percentage terms (e.g. 90% truck, 10% rail) and we used that information as a guide to make the mode assumptions noted in the list. We assumed:

- West Coast region plants serve Vancouver by truck;
- Prairie region plants serve Calgary by truck and Winnipeg by rail;
- Central Region plants serve Toronto by truck if within 200 kilometres or off Lake Ontario and by ship if on Lake Ontario and beyond 200 kilometres;
- Quebec plants serve Montreal 75% by truck and 25% by rail; and
- Nova Scotia plants serve Halifax by truck and Newfoundland plants serve Halifax by ship.

The weighted average transportation distances by mode shown in Table 4.5 were then developed using the distances of each plant from the designated cities and assuming an empty backhaul (i.e. the actual distances were doubled in all cases). The empty backhaul assumption is consistent with the fact that most finished cement moves to markets in specialized bulk transporters, with only a relatively small percent bagged before shipment. Our ultimate focus is on cement used to make concrete for new construction, which means it is on cement moving to ready mixed and pre-cast concrete plants. Virtually all of that cement moves in bulk form.

Table 4.5
WEIGHTED AVERAGE TRANSPORTATION DISTANCES AND MODES FOR FINISHED CEMENT
(kilometres per tonne)

	DISTANCE BY MODE		
REGION	Truck	Rail	Ship
West Coast			
Vancouver	114.39		
Prairie			
Calgary	316.46		
Winnipeg		2620.00	
Central			
Toronto	97.15		136.35
East			
Montreal	182.06	60.69	
Halifax	184.80		303.60

The above distances by mode were converted to the energy estimates shown in Table 4.6 by applying the tonne/kilometre energy consumption figures used for raw material transportation (see Section 4.1).

We should make clear that the averages in Tables 4.5 and 4.6 only reflect where cement is produced and how it is moved. They do not reflect cement consumption levels in any of the cities. Both tables can be interpreted by thinking in terms of the embodied final transportation mileage and energy in a representative or average tonne of cement landed in any one of the six cities. For example, Table 4.5 says that an average tonne of cement in Montreal embodies 182.06 truck kilometres plus 60.60 rail kilometres of finished product transportation, which means a total of 0.24457 GJ of final transportation energy.

Table 4.6
WEIGHTED AVERAGE TRANSPORTATION ENERGY FOR FINISHED CEMENT
(GJ/ tonne)

REGION	ENERGY FORM Diesel - Road	Diesel - Rail	HFO - Marine
West Coast			
Vancouver	0.13498		
Prairie			
Calgary	0.37342		
Winnipeg		1.28380	
Central			
Toronto	0.11464		0.01636
East			
Montreal	0.21483	0.02974	
Halifax	0.21806		0.03643

We have omitted national averages from Tables 4.5 and 4.6 because national averages would be unduly distorted by the absence of any weights to take account of relative consumption levels in different cities and regions. If consumption is not taken into account, the high transportation energy associated with moving cement to a city like Winnipeg would be given too much implicit weight when calculating national averages. In contrast, the earlier sub-sections deal strictly with aspects of production, and kiln capacities provide an adequate weighting mechanism even at the national level. The omission of national averages at this stage, and subsequently, has no bearing in terms of our ultimate focus which is on unit factors for cement delivered to the individual cities.

4.4 ENERGY SUMMARY

Table 4.7 summarizes all of the preceding energy estimates by processing stage in GJ per tonne of finished cement and Table 4.8 shows the percentage of total energy use accounted for by each process stage.

Table 4.7
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION BY PROCESS STAGE
(GJ/tonne of finished cement)

REGION	PROCESS STAGE Raw Material Extraction	Raw Material Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.04464	0.09041	4.68889	0.13498	4.95892
Prairie					
Calgary	0.04455	0.22543	4.30586	0.37342	4.94926
Winnipeg	0.04455	0.22543	4.30586	1.28380	5.85964
Central					
Toronto	0.04451	0.06829	4.44557	0.13100	4.68937
East					
Montreal	0.04417	0.02365	5.52673	0.24457	5.83912
Halifax	0.04417	0.02365	5.52673	0.25449	5.84904

Table 4.8
PERCENT OF ENERGY USE IN CEMENT PRODUCTION BY PROCESS STAGE (%)

REGION	PROCESS STAGE Raw Material Extraction	Raw Material Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.90	1.82	94.55	2.72	100.00
Prairie					
Calgary	0.90	4.55	87.00	7.54	100.00
Winnipeg	0.76	3.85	73.48	21.91	100.00
Central					
Toronto	0.95	1.46	94.80	2.79	100.00
East					
Montreal	0.76	0.41	94.65	4.19	100.00
Halifax	0.76	0.40	94.49	4.35	100.00

Obviously the manufacturing stage is the most critical in terms of energy use in cement production, accounting for about 95% of the energy embodied in cement delivered to cities in most regions. However, the raw material and final cement transportation energy requirements are the second most important element and are particularly notable in the Prairie region.

As indicated in Table 4.2, the pyroprocessing step accounts for most of the manufacturing energy, ranging from 85% in the West Coast region to 89% in the East region. As discussed in Section 2.1, the industry has made substantial energy efficiency gains by shifting from wet processes to dry processes with preheaters and/or precalciners. Table 4.9, which shows the relative energy efficiencies of the different processes on a national weighted average basis, illustrates the extent of those gains .

Table 4.9
WEIGHTED AVERAGE PYROPROCESSING ENERGY BY PROCESS TYPE (GJ/tonne of finished cement)

PROCESS TYPE	GJ/tonne
Wet	5.91342
Dry Long	5.09860
Dry Preheater	3.36002
Dry Precalciner	3.25898

A dry precalciner process uses only about 55% of the energy used by a wet process and a little less than 65% of the energy used by the dry long process. These differences between the process type are the primary explanation for the regional variations in the level of manufacturing energy use noted above (i.e. the mix of process types varies by region).

We should caution that care needs be taken when comparing the above energy estimates by process type with estimates prepared by others: process energy requirements are often cited in terms of energy required to produce a tonne of clinker, while the estimates presented here are per tonne of finished cement.

The final summary table, Table 4.10, shows weighted average energy use in terms of the fuel types aggregated for all production stages. The underlying breakdown of this data by activity stage is used for the estimation of atmospheric emissions in a later section of the report.

Table 4.10
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION BY ENERGY FORM
(GJ/tonne of finished cement)

REGION	ENERGY FORM									TOTAL
	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	
West Coast										
Vancouver	0.187	0.001	0.082	2.303	1.463	0.155	0.196	0.00	0.571	4.959
Prairie										
Calgary	0.454	0.188	0.00	3.666	0.00	0.00	0.00	0.00	0.640	4.949
Winnipeg	0.081	1.472	0.00	3.666	0.00	0.00	0.00	0.00	0.640	5.860
Central										
Toronto	0.188	0.006	0.048	0.582	2.269	0.081	0.631	0.266	0.619	4.689
East										
Montreal	0.274	0.030	0.008	0.774	1.663	0.848	1.187	0.469	0.586	5.839
Halifax	0.277	0.00	0.044	0.774	1.663	0.848	1.187	0.469	0.586	5.849

Note: Totals may not add due to rounding.

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[1]*Canadian Industry Program for Energy Conservation (CIPEC)* (Ministry of Energy, Mines and Resources Canada, 1989).
[2]D. Gardner, Y. Chung and LBuja-Bijunas, *An INDEPTH model of Ontario Cement Industry*, (Ontario Hydro, December 1989).
[3]*Canadian Plant Information Summary - 1991* (U. S. Portland Cement Association and Canadian Portland Cement Association, August 1992), pp. 102-132.
[4]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993).
[5]*U. S. and Canadian 1991 Labor - Energy Input Survey* (Canadian Portland Cement Association, September 1992), pp. 1 - 19.

5.0 ATMOSPHERIC EMISSIONS

This section addresses atmospheric emissions associated with the production of portland cement in all its processing stages, from the extraction and transportation of raw materials through manufacturing and final transportation to markets.

Like any energy-burning production process, cement production generates common air pollutants including carbon dioxide (CO_2), sulphur oxides (SO_x) — primarily sulphur dioxide (SO_2) — nitrogen oxides (NO_x), volatile organic compounds (VOC), methane (CH_4), and carbon monoxide (CO) as well as total particulate matter (TPM). These energy-related emissions are termed “fuel emissions”.

In addition, the specific characteristics of cements and the nature of high temperature cement manufacturing result in other positive and negative atmospheric emission effects. There is a significant “calcination CO_2” contribution due to the decomposition of limestone in the manufacturing of cement, as well as “thermal” and “prompt” NO_x contributions, usually outweighing the “fuel” NO_x. On the positive side, during its production cement has the ability to absorb (scrub) almost all the SO_x generated from both the raw materials and fuels used, allowing the use of high sulphur content fuels that could not be used in other processes unless a flue gas desuphurization (FGD) step was implemented. These aspects will be discussed in more detail in the sub-sections dealing with the individual emissions.

As in the energy section of the report, all results are presented in terms of weighted averages developed for the four geographical regions (West Coast, Prairies, Central and East), and adjusted to take account of transportation of the cement to the six cities (Vancouver, Calgary, Winnipeg, Toronto, Montreal and Halifax), following the same assumptions regarding shipping distances and modes of transportation.

Only a limited amount of data on measured atmospheric emissions is publicly available from the cement industry. In developing our estimates, therefore, energy factors were estimated based on the Gardner model (see Section 4.2) and necessary corrections and modifications were made to reflect the effects of calcination on the CO_2, SO_x and NO_x levels. Contributions to atmospheric emissions by both the cement production process stages and source of energy/fuel are tabulated and discussed in some detail, including the assumptions made and the reasoning for them. Findings and estimates of emissions in the manufacturing stage are critically compared with the limited data available and published by other researchers.

5.1 APPROACH

With the exception of those related to electricity, energy-related atmospheric emission estimates were developed using the energy estimates by process stage from Section 4 and energy emission factors as given in Tables 3 and 6 of the *Research Guidelines* . Where some values were missing in the *Research Guidelines*, the original sources were consulted.[1] Energy emission factors used throughout this work are summarized in Table 5.1.

Emissions related to the generation of electricity used by the cement industry are not included in the tables that follow in this section. These emissions are being calculated separately within the Sustainable Materials Project calculation model for all of the products under consideration (i.e. concrete, steel and wood). The estimates of electricity

Table 5.1
ENERGY EMISSION FACTORS
(kg/GJ)

	CO_2	SO_2	NO_X	VOC	CH_4	CO
Natural gas	49.700	0.0002	0.0590	0.00120	0.00130	0.01500
Diesel road	70.700	0.1020	0.8070	0.08690	0.02170	0.44300
Diesel rail	70.700	0.1020	1.4000	0.07000	0.00780	0.05700
H.F. oil marine	74.000	0.4500	0.2000	0.36000	0.04000	0.00740
H.F. oil industr.	74.000	0.8375	0.1600	0.00290	0.00082	0.01440
Coal - W. Coast	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
Coal - Prairie	94.300	0.4400	0.2500	0.00150	0.00054	0.09300
Coal - Central	87.600	0.8360	0.2500	0.00150	0.00054	0.09300
Coal - East	85.333	1.7278	0.2500	0.00150	0.00054	0.09300
Coke	86.000	1.1500	0.2400	0.00140	0.00051	0.08800
Waste	67.500		0.1200	0.00120	0.00110	
Electricity	*84.263*	*2.6130*	*0.7430*	*0.00400*	*0.00100*	

use in cement and concrete production presented in this report will be translated into the mix of primary energy forms used to generate the electricity for the relevant regional electrical systems. Corresponding atmospheric emissions will be then added in the model to the other emissions estimated in this study.

However, because of the importance of electricity use in cement production and to ensure the completeness of this report, we have developed preliminary estimates of the electricity-related atmospheric emissions in the various steps of cement production and have included those estimates in a set of tables in Appendix A. The appendix tables correspond to key tables in this section, with electricity-related emissions added to the appropriate emission categories. The electricity emission factors were taken from an earlier draft (September 1990) of the EMR report cited above as the source for the other emission factors in Table 5.1.

Coal emission factors for the Central and Eastern regions were developed in the following manner. We assumed that all the coal is the bituminous type, and that in the Central region 30% is domestic coal, and 70% is imported, in accordance with the data presented in the *1990 Canada Minerals Yearbook* .[2] For the Eastern region, blended factors were used, based on a Quebec/Maritimes ratio of cement production of 85/15 and the assumption of a 30/70 split for domestic versus imported coal for Quebec, and 100% domestic coal for the Maritimes.

5.2 ATMOSPHERIC EMISSION ESTIMATES

5.2.1 Raw Materials Extraction

Raw materials extraction (usually quarrying in open pit operations) involves drilling and blasting, with fractured rock handled and loaded onto trucks using front-end loaders, mechanical shovels and traxcavators. All this equipment uses diesel fuel. Atmospheric emissions were estimated using the weighted average energy estimates for raw materials extraction (Section 4.1) together with appropriate diesel road emission factors.

Drilling, blasting and loading operations also create dust emissions. Environment Canada's report entitled *A Nationwide Inventory of Emissions of Air Contaminants* [3] quotes particulate emission factors taken from a U.S. Environmental Protection Agency (EPA) paper.[4] For open-pit mining, a particulate emission factor of 0.51 kg/tonne is given. This factor was used to estimate weighted averages for total particulate emissions due to raw materials extraction.

It should be noted that the EPA extraction emissions factor also includes particulate emissions due to raw materials transportation. However, as the transportation particulate emissions are rather small in comparison to the extraction dust emissions, we felt that using the EPA numbers results in only a small error in the allocation of particulate emissions and, what is more important, both particulate emissions are still captured in the totals.

Although blasting agents also generate some nitrogen oxides and some hydrocarbons, these emissions do not contribute significantly to the pollution burden, and are considered to be negligible.[5]

Total estimated atmospheric emissions due to cement raw materials extraction are shown in Table 5.2

Table 5.2
ATMOSPHERIC EMISSIONS DUE TO CEMENT RAW MATERIALS EXTRACTION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
West Coast	Vancouver	3155.90	4.55	36.02	3.88	0.97	19.77	843.03
Prairies	Calgary	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
	Winnipeg	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
Central	Toronto	3146.97	4.54	35.92	3.87	0.97	19.72	840.99
East	Montreal	3122.92	4.51	35.65	3.84	0.96	19.57	834.20
	Halifax	3122.92	4.51	35.65	3.84	0.96	19.57	835.17

TPM - total particulate matter

5.2.2 Raw Materials Transportation

Raw materials transportation energy unit factors based on information provided directly by most cement manufacturing operations were shown in Section 4.1, Table 4. These factors were multiplied by the appropriate emission factors from Table 5.1. The resulting raw materials transportation emissions estimates are presented in Tables 5.3. Table A.1 in Appendix A shows the corresponding estimates when preliminary electricity-related emissions are added. As noted above, particulate emissions related to raw material transportation are included in Table 5.2.

Table 5.3
ATMOSPHERIC EMISSIONS DUE TO CEMENT RAW MATERIALS TRANSPORTATION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_X	VOC	CH_4	CO
West Coast	Vancouver	6628.35	37.71	23.11	30.20	3.44	3.90
Prairies	Calgary	15881.67	22.91	293.04	16.34	2.25	26.77
	Winnipeg	15881.67	22.91	293.04	16.34	2.25	26.77
Central	Toronto	4787.51	17.76	37.55	14.30	1.94	13.42
East	Montreal	1616.61	5.06	13.33	4.12	0.63	6.51
	Halifax	1616.61	5.06	13.33	4.12	0.63	6.51

5.2.3 Cement Manufacturing

Atmospheric emissions are generated in all steps of the cement manufacturing process described in Section 2.1 of this report. Use of energy to drive the crushers, ball mills, roller mills, the various conveyors and roller presses, and especially fuel combustion in the calcination step, generates all the common air pollutants (i.e. CO_2, SO_2, NO_X, VOCs, CH_4 and CO) usually associated with energy consumption. In addition, the chemical composition of the raw materials as well as unique characteristics of the manufacturing process itself, significantly affects the amounts of CO_2, SO_2 and NO_X released — negatively in the case of CO_2 and NO_X, but positively in the case of SO_2. Particulate matter is also generated as raw materials are reduced to fine particles through crushing and grinding (typically to 75–80% finer than 75 µm/200 mesh), and as this fine powder is processed in the rotary kiln, cooled and ground into cement.

Permissible levels of SO_2 and NO_X as well as of particulate emissions are regulated by the provinces. According to industry sources, monitoring of air quality near cement plants indicates that the current emission limits are not exceeded.[6] The emission of CO_2 has not been regulated so far.

Weighted averages of estimates for atmospheric emissions due to the manufacturing stage of the cement production are summarized in Table 5.4. Comparable estimates with electricity-related emissions added are shown in Table A.2 in Appendix A.

Table 5.4
ATMOSPHERIC EMISSIONS DUE TO CEMENT MANUFACTURING
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
West Coast	Vancouver	779160.25	38.84	4447.38	5.68	4.01	188.15	483.06
Prairies	Calgary	680558.86	0.06	5422.31	4.40	4.77	52.71	938
	Winnipeg	680558.86	0.06	5422.31	4.40	4.77	52.71	938
Central	Toronto	804194.66	104.40	1661.74	5.54	2.66	273.95	340.32
East	Montreal	875240.59	192.04	2870.47	8.11	3.72	280.31	863.23
	Halifax	875240.59	192.04	2870.47	8.11	3.72	280.31	603

The main emissions are discussed in more detail in the following sub-sections, including the specific findings, assumptions and methods underlying the estimates shown in Table 5.4. The discussions also include comparisons of our estimates with the limited data available in the literature.

Carbon Dioxide (CO_2)

The cement industry is a major generator of CO_2. In general, 1 tonne of CO_2 is generated in the production of 1 tonne of portland cement. According to Davidovits: "In 1987, 1-billion tonnes world production of cement accounted for 1-billion tonnes of CO_2, i.e. 5% of the total 1987 world carbon dioxide emissions. To put this number in perspective, this is equivalent to the CO_2 generated by the entire Japanese industrial activity."[7] According to Holderbank, the Canadian cement industry produced about 8.9 million tonnes of CO_2 in 1990, which was about 2% of total Canadian CO_2 emissions.

There are two sources of CO_2 encountered in cement production: *fuel* CO_2 and *calcination* or *chemical* CO_2. As its name implies, fuel CO_2 is caused by burning fossil fuels and the use of electrical energy in the manufacturing process. The fuel CO_2 level can be estimated as a product of the quantity and type of fuels used and an appropriate emission factor from Table 5.1.

Depending on the source of fuel, significant differences in fuel CO_2 are possible. Natural gas CO_2 emissions at 49.7 kg/GJ are substantially lower than those for heavy fuel oil at 74 kg/GJ and coal in the 85.3–94.3 kg/GJ range. But availability, economics and other considerations favour the use of coal over natural gas as a primary kiln fuel. The Portland Cement Association (PCA) in its 1991 Energy Input Survey reports that coal's share of energy consumption has risen from 9.9% in 1974 to 56.2% in 1991, while petroleum products have declined from 36.6% to 3.2%.[8] Natural gas at 27.3% is now the second most widely used fuel type.

The calcination CO_2 is generated in the kiln during pyroprocessing. Calcium carbonate ($CaCO_3$) contained in limestone breaks down into calcium oxide (CaO) and carbon dioxide (CO_2) that is released into the atmosphere. It is generally agreed that the world average value of the CaO content in portland cement is between 60 and 67% .[9] Using 63.5% as a fair value for calcium oxide in cement, it is possible to estimate the calcination CO_2 emission factor by dividing the molar mass of carbon dioxide (CO_2) by the molar mass of calcium oxide (CaO) and multiplying this by the fraction of CaO contained in cement (0.635):

$$44.00995 \text{ g/mole } CO_2 \text{ / } 56.0794 \text{ g/mole CaO x } 0.635 = 0.498335 \text{ t } CO_2 \text{ per t of cement}$$

Until relatively recently, the total CO_2 emissions from the cement industry were almost equally distributed between the fuel CO_2 and calcination CO_2. While the Canadian cement industry has improved its overall efficiency over the past two decades, it has, at the same time, changed its fuel profile toward higher percentages of coal and petroleum coke. The increased use of coal and coke has meant a higher specific volume of CO_2 generated per unit of energy used. Both the improved energy efficiency and the switch to coal directly affect the amount of CO_2 generated per tonne of clinker produced.[10] Since 1974, the improved fuel efficiency has reduced the fuel-generated CO_2 emissions by approximately 13%, but the improved efficiency of the Canadian industry has caused a shift in the calcination CO_2 to fuel CO_2 ratio from 50/50 to about 60/40.

Estimates of the weighted CO_2 emissions for the manufacturing stage (i.e. crushing, raw grinding, calcining and finished grinding) from calcination compared to fuel use, shown in Table 5.5, confirm the shift in the Canadian cement industry. The table also shows total CO_2 from cement production, including extraction and transportation contributions to CO_2 as well as the manufacturing contributions. A comparable table with electricity-related emissions added is provided in Appendix A, Table A.3.

The Holderbank report estimates the total manufacturing CO_2 generated by the Canadian cement industry to be approximately 461 Nm^3/tonne[11] of clinker.[12] This corresponds roughly to 842,957 g of CO_2 per tonne of cement. There appears to be an excellent agreement with the estimates generated by this study.

As noted earlier, CO_2 emissions have not been regulated up to now. Therefore, there has been little effort on the part of the worldwide cement industry to develop technologies solely for the reduction of CO_2.[13] With growing awareness of the contribution of CO_2 to the greenhouse effect and global warming, however, increased pressure to regulate the CO_2 emissions is expected. It would appear that a reduction in CO_2 generation is a challenge for the 21st century. The Holderbank report echoes the feeling of the industry

Table 5.5
FUEL AND CALCINATION CO_2 EMISSIONS FROM CEMENT MANUFACTURING
(g/tonne of cement)

Region	City	Calcination CO_2	Fuel Manufact. CO_2	Total Manufact. CO_2	Calcination as % of Total Manufact. CO_2	Grand Total CO_2
West Coast	Vancouver	498334.83	280825.41	779160.25	63.96	798487.60
Prairie	Calgary	498334.83	182224.02	680558.86	73.22	725991.01
	Winnipeg	498334.83	182224.02	680558.86	73.22	790354.88
Central	Toronto	498334.83	305859.82	804194.66	61.97	821444.83
East	Montreal	498334.83	376905.75	875240.59	56.94	897271.21
	Halifax	498334.83	376905.75	875240.59	56.94	898092.78

that with present technologies, commercialization of plants to produce CO_2 products from kiln exhaust gases does not appear to be economically attractive. For now, reduction in the specific fuel consumption required to make cement is the only means the cement industry has to reduce CO_2 emissions. With the projected decrease in fuel consumption, using 1990 as a benchmark, it is expected that total manufacturing CO_2 unit emissions will drop by about 4.5% and 7% by the years 2000 and 2010, respectively.[14]

There appear to be several options to further decrease the calcination CO_2 contributions. These include:

- increased use of blended cements, in which some portland cement is replaced by cementitious and pozzolanic industrial by-products like fly ashes, blast furnace slags, or silica fume;
- increased use of some of these by-products to partially replace some of the limestone in portland cement raw materials mixes;
- development of new types of cements, like low-CO_2 geopolymeric cements having substantially lower CO_2 liabilities[15], although substantial research work would be needed in this area; and
- development of activated slag cements in which blast furnace slags are activated by chemical admixtures.

Sulphur Dioxide

In the cement manufacturing process, oxides of sulphur are produced by:

- the combustion of sulphur in fossil fuels; and
- the oxidation of sulphates, sulphides and organic sulphur in the cement raw materials.

The total output of sulphur from modern kiln systems ranges typically between 5 and 12 g of SO_x/kg of clinker.[16] According to Holderbank, other factors influencing SO_x emissions include the amount of sulphur relative to alkalis, the conditions of combustion, the kiln type, and the utilization of exhaust gases for drying.

The sulphur oxides can take two forms, SO_2 and SO_3. Nielsen, however, reports that due to the low retention time of exhaust gases at low temperatures in the cement kiln and raw grinding systems, more than 99% of the sulphur is emitted in the SO_2 form, and most of the measured or estimated data make reference to SO_2 emissions only.[17]

The portland cement industry is in the unusual position of being able to utilize high sulphur fuels while still maintaining low sulphur dioxide emissions, a situation in sharp contrast to that of the electrical power-generating stations and other major industries using fossil fuels.

Limestone, which represents the largest part of the raw materials fed into the kiln in the manufacture of cement clinker, significantly reduces the actual amount of SO_2, due to its inherent chemical capacity to react with SO_2. Most of the SO_2 formed by the fuel combustion process is scrubbed by the CaO formed during the calcination process:

$$CaO + SO_2 + 1/2\ O_2 \rightarrow CaSO_4$$

Data obtained in a study which measured uptake of fuel sulphur by portland cement clinker and collected dust compared to that released as gaseous emissions, reported at a joint meeting of the Air Pollution Control Association and Cement Technical Committee of the American Mining Congress, and referred to in the E. Gagan survey[18], shows 86.2 to 99.8% of total fuel sulphur input to be retained in the process. The weighted sulphur retention average of ten operations using different types of fuel with sulphur contents ranging from 0.47–3.0% S was 96.12%. The Holderbank report, quoting another source, reports cement kiln calcination scrubbing potential to be in the 70–95% range.[19]

Nielsen also states that due to the scrubbing effect of limestone, nearly all the SO_2 formed in the kiln is absorbed by the raw material and reintroduced in the kiln.[20] However, under certain circumstances, SO_2 emissions can arise. Where raw materials contain more than 0.2% non-sulphates (such as pyrites, FeS_2) complete reabsorption of SO_2 may not be feasible due to lower temperatures and lower concentrations of free lime in the upper stage cyclones of preheater and precalciner kilns. Also, the kiln gas by-pass can contribute significantly to the total emissions of SO_2 from modern kiln systems.

It should be mentioned that even in the countries with the most stringent SO_2 emission limits, like Germany or Switzerland (400–500 mg/Nm^3)[21], which according to Gagan corresponds roughly to 0.9 kg of SO_2 per tonne of clinker, many of the plants do not use special control systems to meet these compliance levels.

Table 5.6 shows what the pyroprocessing SO_2 emissions would be if it were not for the scrubbing effect of the cement process. The table also shows the corrected pyroprocessing, total manufacturing and total cement production SO_2 emissions. The corrections were made based on Gagan's reported 96.12% scrubbing effect of cement kilns. Table A.4 in Appendix A shows the comparable estimates with electricity-related emissions added.

The previously cited Holderbank report, based on the available test data and reports written on the subject of SO_2 emissions where elevated levels of sulphides are not present in the raw material feed, gives the range of values for SO_2 between 185 and 1,110 g/tonne of cement. The estimates of this study for corrected pyroprocessing SO_2 generally fit into this range, and therefore give credibility to the overall estimates of total cement production SO_2 emissions.

Table 5.6
SO_2 CEMENT MANUFACTURING EMISSIONS CORRECTED AS PER GAGAN[22]
(g/tonne of cement)

Region	City	Pyroproces. Fuel SO_2	Corrected Pyroproces. SO_2	Cor. Total Manufact. SO_2	Cor. Grand Total SO_2
West Coast	Vancouver	1000.24	38.81	38.84	94.87
Prairies	Calgary	0.70	0.03	0.06	65.60
	Winnipeg	0.70	0.03	0.06	158.46
Central	Toronto	2689.76	104.36	104.40	145.75
East	Montreal	4948.64	192.01	192.04	226.55
	Halifax	4948.64	192.01	192.04	240.24

Nitrogen Oxides

Oxides of nitrogen (NO_x) are formed during fuel combustion by oxidation of the nitrogen in combustion air and nitrogen compounds in the fuel. The formation of NO_x is common to most combustion processes.

There are three mechanisms of NO_x formation: thermal NO_x, prompt NO_x, and fuel NO_x.[23] Combustion NO_x control technologies reduce NO_x by inhibiting one or more of these NO_x formation mechanisms. Thermal NO_x is formed under fuel-lean conditions by high temperature reactions between N_2 and O radicals, and can be minimized by reducing the flame temperature. Prompt NO_x is formed under fuel-rich conditions by reactions between N_2 and CH radicals to form HCN, which later can be oxidized to NO_x, and can be minimized by decreasing the residence time under fuel-rich conditions. Fuel NO_x is formed when N in the fuel reacts to form HCN under fuel-rich conditions, and HCN subsequently reacts to form NO_x under fuel-lean conditions. Fuel NO_x can be minimized by increasing the residence time under fuel-rich conditions, where a portion of the HCN is converted to N_2 rather than NO_x. Both prompt NO_x and fuel NO_x are not strongly temperature-dependent. Fuel NO_x formation depends on the nitrogen content of the fuel.

NO_x emissions from cement kilns have been found to depend on both the kiln type and the fuel type. Coal-fired cement kiln NO_x emissions vary between 1 and 3 kg NO_2/tonne clinker.[24] In general, preheater and precalciner kilns have lower NO_x emission rates than long dry and wet kilns, due to the higher fuel efficiency and lower firing rates in the kiln firing zone. Gas-fired kilns have higher NO_x emissions than coal-fired kilns: 7 to 10 kg NO_2/tonne of clinker for long dry kiln type, for example, in comparison with about 2.5 to 3 kg of NO_2/tonne of clinker for coal fired kilns of the same type, in spite of the lower nitrogen content of the fuel. This is because, in cement kilns, the thermal NO_x formation mechanism dominates over the fuel NO_x formation mechanism.

Table 5.7 gives the total pyroprocessing NO_x that has been estimated based on Radian data by Queen et al.[25] Where some information was missing, such as for the gas-fired preheater and precalciner kilns, it was assumed that the relative NO_x emissions in comparison with long dry or wet kilns would be similar to coal-fired kilns. Table 5.8 gives NO_x emission factors from cement kilns used in the estimates, with the extrapolated factors in italics. The version of Table 5.7 with electricity-related NOx added is in Appendix A, Table A.5.

Table 5.7
NO_X CEMENT MANUFACTURING EMISSIONS
(g/tonne of cement)

Region	City	Pyroproc. NO_X	Fuel NO_X	T + P NO_X	Total Manufact. NO_X	Grand Total NO_X
West Coast	Vancouver	4439.56	565.85	3873.70	4447.38	4615.45
Prairies	Calgary	5413.33	207.34	5205.99	5422.31	6052.65
	Winnipeg	5413.33	207.34	5205.99	5422.31	7548.62
Central	Toronto	1652.17	788.20	863.97	1661.74	1831.00
East	Montreal	2860.09	927.94	1932.15	2870.47	3134.45
	Halifax	2860.09	927.94	1932.15	2870.47	3102.71

T + PNOx is thermal + prompt NOx

Table 5.8
NO_X EMISSIONS FROM CEMENT KILNS
(g /tonne of cement)

Fuel	Long Dry	Wet	Preheater	Precalciner
Gas	7631	8325	*4710*	*4800*
Oil	3654	-	NDA	NDA
Coal	2428	1827	1503	1526

NDA = No data available, and not needed for the Canadian cement industry

Fuel NO_X was estimated using the fuel emission factors given in Table 5.1, and the thermal and prompt NO_X were calculated as a difference between the total and fuel NO_X. Weighted averages were calculated for the six specified cities.

At first glance, these estimates appear to be higher than Nielsen's values, ranging typically between 740 and 2775 g/tonne of cement, until one realizes that these numbers are valid only for modern preheater and precalciner kilns, presumably coal fired. The Holderbank study appears to agree that long dry and wet kilns experience higher NO_X emissions (in the 1850–8,325 g/tonne of cement range).[26] In the Canadian industry, with a range of long dry, wet, preheater and precalciner kilns using not only coal, but gas and other kiln fuels as well, the weighted averages are higher. Our numbers seem to confirm the dominance of thermal NO_X over fuel NO_X in cement kilns.

There are two major categories of NO_X control technologies: combustion technologies and post-combustion technologies. Combustion NO_X control technologies are dependent on the NO_X formation mechanisms noted above. Post-combustion technologies are independent of the manner in which NO_X is created.

Post-combustion NO_X control technologies reduce NO_X after it is formed. There are two major classes of post-combustion NO_X control technologies: non-selective and selective. Non-selective reduction technologies are applied in fuel-rich (oxygen-lean) conditions, involve a reaction between NO_X and CO or hydrocarbons to form N_2 and CO_2, and typically require a relatively high temperature (>1300°C) to be effective. There are both non-catalytic and catalytic non-selective reduction technologies referred to as *staged air combustion* (SAC) and *non-selective catalytic reduction* (NSCR). Selective reduction technologies are applied in fuel-lean (oxygen-rich) conditions, and involve a reaction between NO_X and NH_3 (which may come from anhydrous or aqueous NH_3 or urea reagents) to form N_2 and H_2O. Selective reduction technologies include selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR).

Another post-combustion NO_x control technology is wet scrubbing, which involves oxidizing NO_x to NO_2 and scrubbing the NO_2 using basic solution-forming nitrate salts. The NO_2 wet scrubbing technology is only applied cost-effectively to the flue gases containing very high NO_2 concentrations (10,000 ppm range). Clearly, not all of these approaches (notably wet scrubbing) are readily applicable to cement production.

The already quoted Radian study concluded that for cement production, SAC and SNCR approaches provide medium NO_x reduction on some kiln types. SCR shows promise on other types of kilns. In both cases, no effects on clinker quality are indicated.

Particulate Emissions

Particulates are generated by all cement production processes. In order of magnitude and importance the largest amount of particulate matter (TPM) is generated from the kiln, clinker cooler, finish grinding, raw materials preparation and grinding, and bagging and shipping steps.

Cement plants used to be synonymous with primary atmospheric pollution caused by cement dust emissions, with discharged dust visible for miles around every cement plant. That is no longer the case. In developed countries, tremendous strides have been made towards the elimination of particulate matter emissions and, according to Davidovits, "…In Western Europe, USA, Canada, and Japan, today's flue gases are absolutely clean of any dust."[27] The industry has achieved this goal by installing cyclones, electrostatic precipitators and bag filters at virtually every production step.

The best indication of the situation in Canada is the fact that it is now virtually impossible to find any recent data on particulate emissions. The Holderbank study only comments on the fact that the industry meets all the relevant provincial standards and a recent *Environment Canada Inventory* does not even list the cement industry separately as one of the bigger twenty TPM polluters — it is included among "others" and the data are not accessible.[28]

In contrast, a 1974 Environment Canada report on the cement industry was almost entirely devoted to particulate emissions.[29] But by that time the industry was already fully committed to cleaning up the dust problem. The extent of that commitment and the gains that have been made are shown in Table 5.9 which presents actual data for 1970, an industry forecast for 1975, the results of a survey in 1978 and a current estimate.

The current estimate in Table 5.9 was developed using recent data on TPM emissions obtained through provincial ministries of environment (Ontario and Quebec) and through Environment Canada in British Columbia. For the Prairies and the Atlantic provinces, where no up-to-date information was received, it was assumed that similar strides in reduction of TPM were made as in the other regions: that in the Prairies region current TPM are 30%, and in the Atlantic Region 50%, of those reported by Jacques for 1978.

It is expected that regulations calling for further reduction in particulate emissions from the industry will be in force in selected urban areas by the year 2000. If legislation similar to that coming into effect for non-attainment areas in the U.S.A. should be

Table 5.9
PARTICULATE EMISSIONS
(g/tonne of cement)

Region	City	1970[1]	1975 fcst[1]	1978[2]	Current[3]
West Coast	Vancouver	12566*	3663 *	835	483.06**
Prairies	Calgary	12566*	3663 *	3126	938.00
	Winnipeg	12566*	3663 *	3126	938.00
Central	Toronto	12982	352	392	340.32
East	Montreal	26622	3501	12220	863.23
	Halifax	12566*	3663 *	1206	603.00

Notes: * balance of Canada
**based on information for Greater Vancouver area only

Sources: 1. E. W. Gagan, *Air Pollution Emissions and Control Technology, Cement Industry* (Environment Canada Report EPS 3-AP-74-3, Ottawa, April 1974).
2. A. P. Jaques, National Inventory of Sources and Emissions of Carbon Dioxide (Environment Canada Report EPS 5/AP/2, Ottawa, May 1990), pp. XIV - XV, 13.
3. Information from Ontario Ministry of the Environment and Energy, E. Piché, 4/30/93, *Summary of Point Source Emissions from Cement & Concrete Industry (1987) - Tentative;* information from Ministère de l'Environment du Québec, R. Brulotte, 5/6/93; information from Environment Canada, Pacific and Yukon Region, M. D. Nassichuk, 3/31/93; and Environment Canada, *Residual Discharge Information System* (RDIS).

enacted in Canada as well, then certain plants may be required to upgrade their existing control equipment to meet these tighter regulations.[30] There are now improved versions of electrostatic precipitators available, as well as bag filters with highly efficient fabrics. These can be used to further reduce particulate emissions. Of course, this will mean substantial capital expenditures as well as increased consumption of electrical energy.

By way of comparison, in Germany today an average of only about 160 g of dust is released per tonne of cement production.[31]

5.2.4 Finished Cement Transportation

The weighted average atmospheric emissions related to finished cement transportation to distribution centres or ready mixed concrete plants were calculated by combining transportation energy emission factors from Table 5.1 with the estimates of transportation energy use by fuel type presented in Section 4.3. The results are shown in Table 5.10.

Table 5.10
ATMOSPHERIC EMISSIONS DUE TO TRANSPORTATION OF FINISHED CEMENT
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO
West Coast	Vancouver	9543.09	13.77	108.93	11.73	2.93	59.80
Prairies	Calgary	26400.79	38.09	301.35	32.45	8.10	165.43
	Winnipeg	90764.66	130.95	1797.32	89.87	10.01	73.18
Central	Toronto	9315.69	19.06	95.79	15.85	3.14	50.91
East	Montreal	17291.10	24.95	215.00	20.75	4.89	96.86
	Halifax	18112.66	38.64	183.26	32.06	6.19	96.87

It was not possible to develop estimates for particulate emissions due to transportation.

5.3 ATMOSPHERIC EMISSIONS SUMMARY

Total atmospheric emissions related to the production of portland cement are summarized in Table 5.11. Corresponding estimates including emissions related to the generation of electricity used by the industry are shown in Appendix A, Table A.6.

Table 5.11
TOTAL ATMOSPHERIC EMISSIONS DUE TO CEMENT PRODUCTION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	798487.60	94.87	4615.45	51.50	11.35	271.62	1326.09
Prairies	Calgary	725991.01	65.60	6052.65	57.06	16.09	264.64	1779.50
	Winnipeg	790354.88	158.46	7548.62	114.47	18.00	172.39	1779.50
Central	Toronto	821444.83	145.75	1831.00	39.56	8.71	357.99	1181.31
East	Montreal	897271.21	226.55	3134.45	36.82	10.21	403.24	1697.43
	Halifax	898092.78	240.24	3102.71	48.13	11.50	403.25	1438.17

In the preceding discussion of the main emissions (CO_2, SO_2 and NO_x), we compared our estimates with the most important literature references and cited various provincial and federal government emissions data sources. Data from all of these sources has been compiled along with our estimates in a comparative table in Appendix B. Since the various sources do not include emissions related to raw materials extraction or transportation of either raw materials or finished cement, the table includes only our manufacturing emissions estimates for comparison purposes.

One of the major problems with the available data, especially with most of the government sources, is that the estimates appear to be calculated numbers based on theoretical fuel emissions only. Apparently the statisticians assembling these numbers were not familiar with the cement industry and cement chemistry and, as a result, have usually greatly overestimated SO_2 emissions and underestimated NO_x emissions. However, some of the British Columbia numbers are *measured* as opposed to *calculated* emissions and appear to be closer to the target.

Overall, the comparisons in Appendix B indicate our estimates are well within the range of published cement manufacturing emission estimates.

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[1]*Emission Factors for Greenhouse and Other Gases by Fuel Type: An Inventory* (Energy, Mines and Resources Canada, Ad Hoc Committee on Emission Factors, December 1990).
[2]*1990 Canadian Minerals Yearbook* (Energy, Mines and Resources Canada, Ottawa, 1991), p. 21.8.
[3]*A Nationwide Inventory of Emissions of Air Contaminants* (Environment Canada, Report EPS 3-EP-83-10, Ottawa, December 1983), p. 22.
[4]*Metals Mining and Milling Process Profiles with Environmental Aspects* (U.S. Environmental Protection Agency, EPA-600/2-76-167, Washington, U.S., 1976).
[5]Environment Canada, op. cit.
[6]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993).
[7]Davidovits, J., *CO_2-Greenhouse Warming! What Future for Portland Cement?* (Proc. Emerging Technologies Symposium on Cement and Concrete in the Global Environment, Chicago IL, March 1993).
[8]*U.S. and Canadian 1991 Labor-Energy Input Survey* (Portland Cement Association, Skokie IL, September 1992).

[9]Gagan, E.W., *Air Pollution Emissions and Control Technology, Cement Industry* (Environment Canada Report EPS 3-AP-74-3, Ottawa, April 1974).
[10]Holderbank, op. cit.
[11]The symbol N was used in the reference cited and refers to measurements at normal pressure and temperature (i.e. m^3 at normal temperature and pressure).
[12]Ibid.
[13]Ibid.
[14]Ibid.
[15]Davidovits, op. cit.
[16]EMR, op. cit., p. 21.8.
[17]Nielsen, P.B., *SO_2 and NO_x Emissions from Modern Cement Kilns with a View to Future Regulations* (ZKG, No. 9/91, pp.449-456 [Trans. No.11/91 pp.235-239]).
[18]Gagan, op. cit.
[19]Holderbank, op, cit.
[20]Neilsen, op. cit.
[21]Refers to m^3 measured at normal temperature and pressure.
[22]Gagan, op. cit.
[23]Queen, A.T. et al, *Cement Kiln NO_x Control* (Proc. 1993 IEEE Cement Industry Technical Conference, Toronto, May 1993).
[24]Ibid.
[25]Ibid.
[26]Holderbank, op. cit.
[27]Davidoviits, op. cit.
[28]Kostelz, A. and Deslauriers, M., *Canadian Emissions Inventory of Common Air Contaminants (1985)* (Environment Canada Report EPS 5/AP/3, Ottawa, March 1990).
[29]Gagan, op. cit.
[30]Holderbank, op. cit.
[31]Schmidt, M., *Reduction of Energy Consumption and Emissions by Using High Quality Blended Cements for Concrete* (Proceedings of Emerging Technologies Symposium on Cement and Concrete in the Global Environment, Chicago IL, March 1993).

6.0 LIQUID EFFLUENTS

It is widely believed that the cement industry does not have any significant liquid effluent discharges. Indeed, with the exception of the wet-kiln cement manufacturing process that today represents only 17% of the total Canadian cement producing capacity, none of the cement processing technologies use any process water at all. Even in wet-process cement kilns where the feed is prepared in the form of a slurry containing 30–45% water, the water is evaporated in the process and does not create any significant effluents under normal circumstances.

However, like any other industrial operation, cement plants do use some water to clean equipment and yards. In addition, rainwater washes away cement dust into containment areas and this "cement plant" effluent is regularly discharged. Raw material quarries experience the same conditions, and thus create regular "quarry effluents." Sudden storms can also create "stormwater effluent" at quarries. As a result, some liquid effluents are produced by cement plants and associated operations despite the absence of process effluents. While perhaps negligible in comparison to the atmospheric emissions and solid waste discharges of cement works, these effluents should not be ignored.

We were not able to find any information or references in the literature regarding liquid effluents associated with cement operations . However, the Water Resources Branch of the Ontario Ministry of the Environment was able to provide monitoring data from the MISA program[1], and we had limited verbal confirmation of similar numbers from BC Environment.[2]

The detailed Ontario information is summarized in Tables 6.1. and 6.2 as weighted average liquid effluents factors for the following three sources:

- cement plant effluent;
- quarry water; and
- stormwater.

The data are presented in Table 6.1 in terms of grams per tonne of cement and in Table 6.2 in milligrams per liter of effluent — the more conventional effluent units. In addition to the weighted averages, the tables also show the ranges of effluent values.

From the ranges of liquid effluent amounts, it appears that overall volumes of liquid discharges and pollutant concentrations are plant specific. At the same time, there does not appear to be any pattern related to a particular manufacturing process, nor would one expect any significant effects due to specific plant locations. We therefore assumed the liquid effluents due to cement production in various regions will be similar and that the Ontario estimates presented below can be used for all regions.

To derive the breakdown by process stage, the cement plant effluents are allocated to manufacturing and the quarry and stormwater effluents to the raw material extraction stage. Those allocations have been made in the summary table in Section 8.0 (Table 8.9).

Table 6.1
LIQUID EFFLUENTS DUE TO PRODUCTION OF CEMENT
(g/tonne of cement)

	Cement Plant		Quarry water		Stormwater		Total
	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)
Suspended Solids	118.73	19.52-200.05	93.16	15.17-363.46	0.72	11.13-81.6	212.61
Aluminum	0.48	0.04-1.08	0.30	0.00-0.53			0.78
Phenolics	0.01	0.00-0.01	0.01	0.00-0.02	0.00	0.00	0.01
Oil & Grease	4.27	1.63-6.65	2.55	0.25-12.21	0.00	0.00-0.52	6.83
Nitrate, Nitrite	1.41	0.28-3.10	3.93	0.23-11.09	0.01	0.15-0.97	5.35
DOC*	8.16	0.30-14.67	4.34	0.09-16.63			12.49
Chlorides	137.06	39.5- 353.0	521.87	18.01-1247.5	1.04	2.37-85.50	659.97
Sulphates	253.62	46.0- 868.1	303.82	60.2-1027.6	1.05	3.57-83.03	558.49
Sulphides	0.01	0.00-0.09	0.05	0.00-0.33			0.06
Ammonia, -um			0.86	0.09-1.83			0.86
Phosphorus			0.00	0.00-0.01			0.00
Zinc	0.01	0.00-0.11	0.02	0.00-0.18			0.02

* DOC - dissolved organic compounds
Notes: Calculations assume 59.2% industry utilization ;
Cement plant and quarry water data are based on 365 days/year;
Stormwater data as per occurrence, assumed 7 occurrences per year.

Table 6.2
LIQUID EFFLUENTS DUE TO PRODUCTION OF CEMENT
(mg/L of effluent)

	Cement Plant		Quarry water		Stormwater	
	(wght. avg.)	(range)	(wght. avg.)	(range)	(wght. avg.)	(range)
Suspended Solids	59.04	10.34-150.89	103.70	24.68-219.22	137.62	32.09-249.27
Aluminum	0.16	0.05-0.29	0.76	0.00-1.66		
Phenolics	0.00	0.00-0.01	0.01	0.00-0.03	0.00	0.00-0.01
Oil & Grease	1.41	1.18-2.41	1.77	0.89-3.07	0.67	0.00-1.49
Nitrate, Nitrite	0.42	0.00-0.57	2.90	0.27-6.76	1.96	0.42-5.26
DOC*	2.60	0.45-5.00	2.49	0.27-4.68		
Chlorides	44.92	14.51-134.57	1290.03	17.41-3930.89	162.55	12.78-262.10
Sulphates	104.57	20.14-584.81	217.71	81.48-331.77	163.59	19.28-239.39
Sulphides	0.00	0.00-0.02	0.04	0.00-0.10		
Ammonia, -ium			1.41	0.31-3.46		
Phosphorus			0.01	0.00-0.04		
Zinc	0.00	0.00-0.11	0.00	0.00		
pH	8.30	8.25-8.41	8.21	7.79-8.88	8.84	8.13-10.5

* DOC - dissolved organic compounds
Notes: Cement plant and quarry water data are based on 365 days/year
Stormwater data as per occurrence, assumed 7 occurrences per year
pH is the synbol used to express the acidity or alkalinity of a solution on a scale from 0 to 14, where less than 7 represents the degree of acidity, 7 represent neutrality, and more than 7 represents the degree of alkalinity .

[1]Information from Ontario Ministry of the Environment, Water Resources Branch, G. Rees, 4/19/93, *MISA Monitoring Data for Ontario Cement Plants*.
[2]Verbal information, BC Environment, T. Waklin. 6/2/93.

7.0 SOLID WASTES

The cement industry mainly generates solid waste in the manufacturing stage. However, before considering that aspect in Section 7.2, Section 7.1 briefly discusses the question of solid wastes from raw materials extraction. The final subsection, Section 7.3, balances the picture with a discussion of the industry's use of solid and other wastes.

7.1 RAW MATERIALS EXTRACTION

Overburden, top soil, and subsoil have to be removed before a new quarry can commence operation. The soil used to be resold, but in modern operations it is stockpiled for eventual quarry reclamation and is not considered waste.[1]

In general, quarrying and mining operations can create large amounts of mine spoil — rock material that is not used, but is moved to get to the desired mineral resource.[2] Mine spoils are usually deposited in old surface-mine pits or in mounds. These materials can be physically stabilized and protected from runoff or leaching to varying degrees, but have nevertheless been frequent sources of environmental problems.

In contrast to most mining operations, however, cement raw materials (primarily limestone, clays and shales) are abundantly available and quarrying these materials generates very little waste. In comparison with metals mining, for example, there is no separating, refining or smelting of the desired materials from the rock. In the cement industry, it is the rock itself that is used in its entirety. In general, the extraction of limestone, clay and shale, like other structural materials extracted from pits and quarries (e.g. sand, gravel and crushed stone), results in little environmental contamination although the degree of land disturbance can be substantial.[3]

7.2 Cement Manufacturing

The main solid waste generated during the cement manufacturing stages is cement kiln dust (CKD). Another solid waste is spent refractory brick (SRB) from cement kiln linings. Both are discussed in the sub-sections that follow.

7.2.1 Cement Kiln Dust (CKD)

The manufacture of portland cement in rotary kilns includes the tumbling of fine ground raw materials (75–80% finer than 75 µm/200 mesh). This tumbling action releases fine dust particles which are quickly swept out of the kiln by the hot combustion gases.[4] This dust, referred to as cement kiln dust (CKD), is captured by particulate emission control equipment and, if not reused, constitutes solid waste.

Modern dust collection equipment is certified above 98% efficiency for normal operating conditions, and some collectors have tested as high as 99.98%. Most of the CKD is reintroduced into the kiln either directly in the materials mixture, or with the fuel (insufflation). As a result of the cooling associated with the dust capture, the CKD provides nucleation sites for metals and minerals volatilized in the kiln system.[5] The reintroduction of cement kiln dust back into the kiln therefore increases the concentration of alkalis, chlorides and sulphates.

Volatilized alkali chloride and sulphate compounds, if not controlled, condense and accumulate in undesired locations, thereby plugging the cyclones and ducts.[6] In the design of many dry-process kilns, this often necessitates the installation of alternative systems for removing volatilized alkali chlorides and sulphates. Commonly known as alkali bypass systems, these systems operate by removing gases from the kiln at the point prior to condensation of volatile materials. The bypass gas is then treated separately. Furthermore, alkalis in the dust upset kiln operation by lowering the fusion temperature of the other raw materials, increasing the fluidity of the kiln load. This in turn leads to a reduction of the thickness of the layer of material coating and protecting the refractory lining of the kiln.[7]

To prevent operational problems due to the elevated levels of alkalis, cement plants return most or all the CKD back into the kiln if the total alkali content is below 1% (as Na_2O equivalent). An additional complication due to the alkali in the dust is the fact that most of the alkalis returned to the kiln eventually will find their way into the clinker and lead to the production of clinker with alkali levels above the 0.6% level (as Na_2O equivalent), which is the upper limit in specifications for low-alkali cements.[8]

The chemical composition of CKD is determined by the composition of the raw materials, the fuels and the conditions the dust particles have encountered in the kiln. A recent PCA study of cement kiln dust has provided the typical composition of CKD shown in Table 7.1.[9]

Table 7.1
TYPICAL COMPOSITION OF CEMENT KILN DUST

Constituent	% by weight
$CaCO_3$	55.5
SiO_2	13.6
CaO	8.1
K_2SO_4	5.9
$CaSO_4$	5.2
Al_2O_3	4.5
Fe_2O_3	2.1
KCl	1.4
MgO	1.3
Na_2SO_4	1.3
KF	0.4
Other	0.7
Total	100.0

Careful analysis of a dust sample will reveal a variety of elements, some present in only trace concentrations. A pioneering work in this area was the 1982 U.S. Bureau of Mines study.[10] That work concluded that: “Cement kiln dust is a large-volume material and a potential resource as a substitute for lime. Any environmental considerations are minor, as the results of this extensive survey show that U.S. CKD is not a hazardous waste as defined by current regulations established under the U.S. Resource Conservation and Recovery Act (RCRA).”

The Portland Cement Association’s 1992 study was intended as an update and expansion of the Bureau of Mines survey, reflecting the effects of changes in the manufacturing process, raw materials, fuels and testing procedures that have occurred over the past decade.[11] From the perspective of the present study it is important to note that the PCA report included not only 79 U.S. plants, but also 10 Canadian operations. The concentrations of twelve metals — mercury, selenium, thallium, cadmium, lead, antimony, silver, arsenic, nickel, barium, beryllium and chromium — were measured in both cements and CKD. Both total concentrations and Toxicity Characteristics Leaching Procedure (TCLP) tests measuring the propensity for metals to leach from solid materials such as CKD or cement were determined. Over 2200 leachable metals analyses were performed. No cement exceeded the EPA RCRA regulatory action limits. With regard to leaching tests on CKD, one facility produced two CKD samples that exceeded the selenium limit and another facility produced two CKD samples that exceeded the lead limit. The elevated levels for these two relatively volatile metals were attributed to the fact that relatively little CKD was discarded at those facilities. Most of their CKD was returned to the kilns, and thus volatile metals accumulated in the recirculating CKD. Simple doubling the amount of discarded CKD would half the lead and selenium concentrations in CKD at those facilities.

The PCA study also confirmed the results of the Bureau of Mines study concluding that CKD is a non-hazardous waste. It also found that the single most important factor in determining the concentration of metals in CKD is the extent of CKD recirculation.

Unfortunately, very little information is publicly available about how much cement kiln dust is produced and discarded as waste. The PCA study, describing a typical material balance for a dry-process operation producing 5% CKD, gives the breakdown shown in Table 8.2.[12]

Table 7.2
TYPICAL MATERIAL BALANCE

	Constituent	**Throughput [tonnes per hour]**
Inputs	Raw material to kiln	100
	Fuel burned	10
Outputs	Clinker produced	60
	CKD produced	**5**
	Gaseous calcination and combustion products	45

In other words, the CKD produced can be expressed as 5% of the kiln feed, or 8.33% of the clinker produced. Davis and Hooks' ten-year-old numbers are higher, indirectly reflecting perhaps the progress that the cement industry has made recently.[13] The average amount of CKD generated (not emitted) appeared to be 12.2% of the kiln feed, or 19.5% of clinker produced. A decade ago, 96% of this dust was removed from the exhaust gases by dust collectors. About 73% of CKD was returned to the cement-making process, the remaining 27% discarded. Sell and Fischbach are of that opinion that "…ideally, the amount of CKD produced can be minimized, but not likely to less than 5% of production under the best conditions with current technology."[14]

To estimate the amounts of CKD discarded as waste, based on these considerations and internal discussions with Radian's specialist on CKD[15], the following assumptions have been made:

1) based on kiln feed, the long dry process generates 5% CKD; the wet process, 10% CKD; and modern preheater/precalciner processes, 1% CKD;

2) on average, 1.6 tonnes of raw materials are required to produce 1 tonne of clinker; 1 tonne of cement contains 0.925 tonnes of clinker; and
3) 73% of CKD dust is recycled, 27% is discarded.[16]

Based on these assumptions, the factors given in Table 7.3 were developed for CKD as solid waste.

Table 7.3
CEMENT KILN DUST (CKD) DISCARDED AS SOLID WASTE

Region	City	CKD as % of kiln feed	Total CKD [kg/t of cement]	Waste CKD [kg/t of cement]
West Coast	Vancouver	3.88	57.424	15.50
Prairies	Calgary	1.87	27.676	7.47
	Winnipeg	1.87	27.676	7.47
Central	Toronto	2.72	40.256	10.87
East	Montreal	5.48	81.104	21.90
	Halifax	4.08	60.384	16.30

According to the CPCA, 100% of CKD is returned to the kiln as feed in most western plants and our estimates for western regions understate recycling. However, our assumed overall average of 73% recycling (point 3, above) may still be reasonable because other plants may recycle at much lower levels. Also, while a portion of cement kiln dust represents "solid waste" from the point of view of the cement industry, not all of this material is landfilled. It can potentially represent a valuable resource for other applications and users.

A range of potential applications have been reported. Davis and Hooks discuss various options for dust utilization: a mineral filler for bituminous paving and roofing materials; flue gas desulphurization; and agricultural applications.[17] Two properties of CKD that make it useful for agricultural purposes are its acid neutralizing capacity and its potassium content. The Holderbank study discusses at some length the so-called "N-Viro Soil" process that turns two undesirable waste products — sewage sludge and CKD — into a product with added value which can be used as a source of agricultural lime, fertilizer, top soil replacement, landfill cover, etc. Apparently, it has won approvals from various environmental regulatory authorities around the world, and a number of production facilities are in operation in the U.S.A.[18], Britain[19] and Australia[20].

At a recent symposium on "Emerging Technologies on Cement and Concrete in the Global Environment" three papers dealing with the beneficial utilization of CKD were presented. The use of CKD as a scrubbing agent replacing lime in flue gas desulphurization (FGD), with potential reintroduction of FGD generated gypsum back into the cement production, was described by Murdock.[21] Preston discussed agricultural applications of CKD[22], while Young described the Passamaquoddy Technology Recovery Scrubber.[23] This technology now operating for over 10,000 hours at the Dragon Product Co. cement plant in Maine uses alkaline CKD previously landfilled at the rate of about 230 tonnes/day to react with and remove acidic SO_2, HCl and CO_2 components from exhaust gas. Over 90% of the SO_2 is removed, as are over 95% of the HCl and lesser amounts of CO_2. Soluble alkali compounds are removed from CKD, upgrading it for reuse as a feedstock in the cement plant. Soluble potassium salt products are used as a fertilizer in agriculture. At $11 million (U.S.) the cost of such a recovery scrubber is substantial.

At this point, both the cost of necessary plant modifications and long-term liability considerations still limit the beneficial reuse of CKD. However, there is little doubt its use will increase in the future.

7.2.2 Spent Refractory Bricks (SRB)

Rotary cement kilns are lined with refractory bricks. Periodically (approximately every two years), cement kilns have to be re-lined and the resulting spent refractory bricks (SRB) constitute solid waste. Traditionally, the bricks were disposed of in landfills, although recently some discussions about their reuse potential have been reported.

No current data are available, but it is certain that spent refractory bricks are far below the 2% input by mass specified in the Research Guidelines for the Sustainable Materials Project as the cut-off point for separately considering input materials.

The only potential problem with SRBs, and the reason they are mentioned here, is the fact that volatilized metals tend to concentrate in them in a similar manner as in recirculated cement kiln dust. If a kiln is not relined for a longer period than customary, and if the raw materials and fuels used have higher than average concentrations of volatile metals, the total leachable metals content could exceed current limits, making SRBs hazardous waste.

7.3 THE USE OF WASTES IN CEMENT MANUFACTURING

It is important to note that the cement industry is in a rather unique position in that it can use various industrial wastes or byproducts, as well as some post-consumer wastes, in its raw materials feed. In addition, because of the high temperature of the kiln some wastes, including some hazardous wastes, can be safely used as fuel.

7.3.1 Industrial Byproducts as Raw Materials

Among the industrial wastes that can be readily used by the cement industry either as a part of its raw materials feed or as ingredients of blended cements are coal combustion byproducts such as fly ash, and blast-furnace slag from the iron industry.[24]

Fly ash is a byproduct of the combustion of pulverized coal in thermal power plants. As a fine particulate residue, it is separated by electrostatic dust collection systems from the combustion gases before their discharge into the atmosphere. About four million tonnes of fly ash are produced each year in Canada from 22 coal fired power plants, about one-hundredth of the total worldwide estimated production. Low calcium content (ASTM Class F) fly ash is being used successfully as a low-alkali kiln feed in the manufacture of cement clinker; it is a rich source of silica and alumina. Fly ash also exhibits pozzolanic characteristics, and it offers some specific in-use technical advantages as an additive in the production of concrete unattainable when ordinary portland cement is used alone. These advantages include improved workability of concrete, reduced heat of hydration, improved water tightness and ultimate strength, as well as enhanced resistance to sulphate attack and to alkali-aggregate expansion.

In the early 1980s, the total utilization of coal ash in Canada was estimated to be 500,000 tonnes, large-scale use being limited mainly to the provinces of Ontario (32% of production) and Alberta (14%).[25] About 50% of this amount was marketed and used as a cement substitute or replacement. The percentage of collected fly ash in cements and concretes in Canada is currently about 7%, rather low compared with 24% in France, 19% in the U.K.[26] or even higher numbers in Holland, but higher than the 6% utilized in the U.S.A.

Blast-furnace slag, a waste product from the manufacture of iron, has a long history of use in cements and concrete in Europe. Prior to 1975, there was no significant use of slag in North America. Only following the oil crisis of the early seventies and rapidly escalating energy, and consequently cement, costs, did blast-furnace slag began to be used in both Canada and the U.S.A.[27] Iron ore blast-furnace slag is a composite product resulting from the reaction of flux stone (limestone or dolomite) with siliceous and aluminous residues from iron ore and coke ash in the production of iron in blast furnaces.

Other byproducts often used as secondary raw materials to adjust the raw feed composition include iron ores, mill scale, foundry sands and spent catalysts.[28] Once the new scrubber comes on stream at Ontario Hydro's Lambton station in 1994 producing quality FGD gypsum, some of that material may find its way into cement production as well, replacing natural gypsum currently shipped from Nova Scotia.

7.3.2 Waste Fuels

Cement kilns can effectively use a wide range of fuels, including many waste-derived fuels, to produce quality cements. Waste-derived fuel (WDF) include such materials as tires, used oil, and energy-rich hazardous wastes.[29] For a given weight, whole or shredded tires have more fuel value than coal.[30] A single cement kiln can burn more than a million tires a year, saving almost 11,000 tonnes of coal. It is estimated that the heating value in scrapped tires alone is sufficient to meet 10% of the fuel requirements of the Canadian cement industry.[31]

Liquid WDF's vary in composition. High-quality kiln fuels can be prepared from waste lubricating oils, paint thinners, solvents, printing inks, cleaning fuels, and chemical byproducts from pharmaceutical and chemical manufacturing. There will be environmental hazards if these materials are improperly managed. But if properly handled, these WDF's decompose at the high temperatures in cement kilns in the same way as fossil fuels into their basic building blocks: carbon, hydrogen, oxygen, nitrogen, sulphur and trace elements.

Today, wider use of WDF is prevented by limitations of current material handling technology and economic constraints, as well as by other factors including a lack of understanding by the general public, the actions of various pressure groups and potential long term liabilities. Although nine out of eighteen Canadian cement plants reported waste fuel usage in 1991, the total energy derived from waste fuel actually declined to only 1.7%.[32] At the same time, WDF usage increased to 7.8% in the U.S.A. and the increased use of waste fuel appears to be a major trend in the industry, following the lead of some overseas countries where some plants often obtain 30–40% of the kiln fuel needs from WDF. It is expected that by the year 2010, potential Canadian usage of WDF could amount to 25% of the cement industry kiln heat input.[33]

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[1]*The State of Canada's Environment* (Environment Canada, Ottawa 1991), p.11-20.
[2]*Environmental Resource Guide*, *Topic I-3110 4* (The American Institute of Architects, Washington DC, October 1992).
[3]Environment Canada, op. cit.

[4]Davis, T. A. and Hooks, D. B., *Study of the State of the Art of Disposal and Utilization of Waste Kiln Dust from the Cement Industry* (EPA-670/2-75-043, NTIS PB 242825, U.S.Dept. of Commerce, 1975).
[5]Murdock, K.J., *The Utilization of Bypass Dust in the Capture of* SO_2 *and the Manufacture of Portland Cement* (Proceedings of the Emerging Technologies Symposium on Cement and Concrete in the Global Environment, Chicago IL, March 1993).
[6]*An Analysis of Selected Trace Metals in Cement and Kiln Dust, Cement and its Production* (Portland Cement Association, Skokie IL, 1992), pp.40-41.
[7]Davis and Hooks, op. cit.
[8]Ibid.
[9]Portland Cement Association, op. cit., p. 50.
[10]Haynes, B. W. and Kramer, G.W., *Characterization of U.S. Cement Kiln Dust* (U.S. Bureau of Mines Information Circular (IC) 8885, Washington DC, 1982).
[11]Portland Cement Association, op. cit.
[12]Ibid.
[13]Davis and Hooks, op. cit.
[14]Sell, N.J. and Fischbach, F.A., *The economic and Energy Costs of Dust Handling in the Cement Industry* (Resource Recovery and Conservation, 3, 1979), pp.331-342.
[15]Verbal information, J. Kamas, Radian Corporation, 8/16/93.
[16]Haynes and Kramer, op. cit.
[17]Davis and Hooks, op. cit.
[18]Murdock, op. cit.
[19]*A Nationwide Inventory of Emissions of Air Contaminants (1978)* (Environment Canada, Report EPS 3-EP-83-10, Ottawa, December 1983).
[20]*Emission Factors for Greenhouse and Other Gases by Fuel Type: An Inventory* (Energy, Mines and Resources Canada, Ad Hoc Committee on Emission Factors, December 1990).
[21]Murdock, op. cit.
[22]Preston, M. L., *Use of Cement Kiln Dust as an Agricultural Lime and Fertilizer* (Proceedings of the Emerging Technologies Symposium on Cement and Concrete in the Global Environment, Chicago IL, March 1993).
[23]Young, G. L., *Use of Cement Kiln Dust for the Capture of* SO_2*, HCl, and* CO_2 *from Flue Gas and Subsequent Production of Fertilizer and Kiln Feed* (Proceedings of the Emerging Technologies Symposium on Cement and Concrete in the Global Environment, Chicago IL, March 1993).
[24]Venta, G. J., Hemmings, R. T. and Berry, E.E., *Green Building Technology, A North American Perspective on Recycling and Reuse of Waste and Industrial Byproducts in Building Materials* (Proceedings of the ReC'93 International Recycling Congress, Geneva, Switzerland, January 1993).
[25]Ibid.
[26]Berry, E. E. , Hemmings, R. T. and Burns, J. S., *Coal Ash in Canada* (CEA Report G195, Canadian Electrical Association Report, 1983).
[27]*Developments in Building Products: Opportunities for Industrial Minerals* (IRC / MATEX Consultants Inc., Background Paper No. 13, Ministry of Northern Development and Mines, Ontario, 1990); and Hooton, R. D. , *The Reactivity and Hydration Products of Blast-Furnace Slag,* (in Supplementary Cementing Materials for Concrete, Publication SP86-8E, editor, V.M. Malhotra, CANMET, Energy, Mines and Resources Canada, Ottawa 1987).
[28]Portland Cement Association, op. cit.
[29]Ibid.
[30]*Putting Waste to Work* (Portland Cement Association, Publication PA165T, Skokie IL, 1992).
[31]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993).
[32]*U.S. and Canadian 1991 Labor-Energy Input Survey* (Portland Cement Association, Skokie IL, September 1992).
[33]Holderbank, op. cit.

8.0 SUMMARY OF CEMENT UNIT FACTORS

This section summarizes the unit factors developed in the preceding six sections. The summary is organized by unit factor category, with subsequent breakdowns by process stage as necessary. For each unit factor category, we simply show the key table or tables from the relevant section, without additional comment. All unit factors are expressed in the relevant units per tonne of finished cement.

Table 8.1
WEIGHTED AVERAGE RAW MATERIAL USE BY REGION
(tonnes per tonne of finished cement)

RAW MATERIALS	REGION: W. Coast	Prairie	Central	Eastern
Limestone	1.17	1.33	1.45	1.31
Clay/Shale	0.32	0.23	0.06	0.18
Iron	0.03	0.04	0.04	0.01
Sand	0.07	0.00	0.02	0.09
Ash	0.01	0.00	0.03	0.00
Other	0.003	0.00	0.00	0.01
Gypsum	0.09	0.08	0.08	0.06
Total	1.69	1.68	1.68	1.66

Table 8.2
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION
BY PROCESS STAGE AND REGION
(GJ/tonne of finished cement)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing	Cement Transportation	TOTAL
West Coast					
Vancouver	0.04464	0.09041	4.68889	0.13498	4.95892
Prairie					
Calgary	0.04455	0.22543	4.30586	0.37342	4.94926
Winnipeg	0.04455	0.22543	4.30586	1.28380	5.85964
Central					
Toronto	0.04451	0.06829	4.44557	0.13100	4.68937
East					
Montreal	0.04417	0.02365	5.52673	0.24457	5.83912
Halifax	0.04417	0.02365	5.52673	0.25449	5.84904

Table 8.3
WEIGHTED AVERAGE ENERGY USE IN CEMENT PRODUCTION
BY ENERGY FORM
(GJ/tonne of finished cement)

REGION	ENERGY FORM: Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste Heat	Electric	TOTAL
West Coast										
Vancouver	0.187	0.001	0.082	2.303	1.463	0.155	0.196	0.00	0.571	4.959
Prairie										
Calgary	0.454	0.188	0.00	3.666	0.00	0.00	0.00	0.00	0.640	4.949
Winnipeg	0.081	1.472	0.00	3.666	0.00	0.00	0.00	0.00	0.640	5.860
Central										
Toronto	0.188	0.006	0.048	0.582	2.269	0.081	0.631	0.266	0.619	4.689
East										
Montreal	0.274	0.030	0.008	0.774	1.663	0.848	1.187	0.469	0.586	5.839
Halifax	0.277	0.00	0.044	0.774	1.663	0.848	1.187	0.469	0.586	5.849

Notes: Totals may not add due to rounding. The breakdowns by process stage are shown in the relevant sections.

Table 8.4
ATMOSPHERIC EMISSIONS DUE TO CEMENT RAW MATERIALS EXTRACTION: BY REGION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	3155.90	4.55	36.02	3.88	0.97	19.77	843.03
Prairies	Calgary	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
	Winnipeg	3149.69	4.54	35.95	3.87	0.97	19.74	841.50
Central	Toronto	3146.97	4.54	35.92	3.87	0.97	19.72	840.99
East	Montreal	3122.92	4.51	35.65	3.84	0.96	19.57	834.20
	Halifax	3122.92	4.51	35.65	3.84	0.96	19.57	835.17

Table 8.5
ATMOSPHERIC EMISSIONS DUE TO CEMENT RAW MATERIALS TRANSPORTATION: BY REGION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO
West Coast	Vancouver	6628.35	37.71	23.11	30.20	3.44	3.90
Prairies	Calgary	15881.67	22.91	293.04	16.34	2.25	26.77
	Winnipeg	15881.67	22.91	293.04	16.34	2.25	26.77
Central	Toronto	4787.51	17.76	37.55	14.30	1.94	13.42
East	Montreal	1616.61	5.06	13.33	4.12	0.63	6.51
	Halifax	1616.61	5.06	13.33	4.12	0.63	6.51

Table 8.6
ATMOSPHERIC EMISSIONS DUE TO CEMENT MANUFACTURING: BY REGION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	779160.25	38.84	4447.38	5.68	4.01	188.15	483.06
Prairies	Calgary	680558.86	0.06	5422.31	4.40	4.77	52.71	938
	Winnipeg	680558.86	0.06	5422.31	4.40	4.77	52.71	938
Central	Toronto	804194.66	104.40	1661.74	5.54	2.66	273.95	340.32
East	Montreal	875240.59	192.04	2870.47	8.11	3.72	280.31	863.23
	Halifax	875240.59	192.04	2870.47	8.11	3.72	280.31	603

Table 8.7
ATMOSPHERIC EMISSIONS DUE TO TRANSPORTATION OF FINISHED CEMENT: BY REGION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO
West Coast	Vancouver	9543.09	13.77	108.93	11.73	2.93	59.80
Prairies	Calgary	26400.79	38.09	301.35	32.45	8.10	165.43
	Winnipeg	90764.66	130.95	1797.32	89.87	10.01	73.18
Central	Toronto	9315.69	19.06	95.79	15.85	3.14	50.91
East	Montreal	17291.10	24.95	215.00	20.75	4.89	96.86
	Halifax	18112.66	38.64	183.26	32.06	6.19	96.87

Table 8.8
TOTAL ATMOSPHERIC EMISSIONS DUE TO CEMENT PRODUCTION: BY REGION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	798487.60	94.87	4615.45	51.50	11.35	271.62	1326.09
Prairies	Calgary	725991.01	65.60	6052.65	57.06	16.09	264.64	1779.50
	Winnipeg	790354.88	158.46	7548.62	114.47	18.00	172.39	1779.50
Central	Toronto	821444.83	145.75	1831.00	39.56	8.71	357.99	1181.31
East	Montreal	897271.21	226.55	3134.45	36.82	10.21	403.24	1697.43
	Halifax	898092.78	240.24	3102.71	48.13	11.50	403.25	1438.17

Table 8.9
WEIGHTED AVERAGE LIQUID EFFLUENTS DUE TO CEMENT PRODUCTION: ALL REGIONS
(g/tonne of cement)

	Raw Material Extraction	Manufacturing	Total
pH	17.05	8.30	25.35
Suspended Solids	93.88	118.73	212.61
Aluminum	0.30	0.48	0.78
Phenolics	0.01	0.01	0.01
Oil & Grease	2.55	4.27	6.83
Nitrate, Nitrite	3.94	1.41	5.35
DOC	4.34	8.16	12.49
Chlorides	522.91	137.06	659.97
Sulphates	304.87	253.62	558.49
Sulphides	0.05	0.01	0.06
Ammonia, -um	0.86		0.86
Phosphorus	0.00		0.00
Zinc	0.02	0.01	0.02

The above effluent estimates are assumed to apply equally to plants in all regions and therefore to cement delivered to all cities of interest.

Table 8.10
SOLID WASTE (CEMENT KILN DUST) DUE TO CEMENT MANUFACTURING: BY REGION
(kg/t of cement)

Region	City	Waste CKD
West Coast	Vancouver	15.50
Prairies	Calgary	7.47
	Winnipeg	7.47
Central	Toronto	10.87
East	Montreal	21.90
	Halifax	16.30

PART 2

CONCRETE PRODUCTS

PART II: CONCRETE PRODUCTS

9.0 THE CONCRETE INDUSTRY: AN OVERVIEW

The focus of the Sustainable Materials Project is on the following final concrete building products:

- 15, 20 and 30 Mpa ready mixed concrete;
- precast ‘double T’ beams with median values for steel and concrete content;
- precast hollow deck with median values for steel and concrete content;
- standard concrete blocks; and
- cement mortar.

The estimates of raw material requirements, energy and water use, atmospheric emissions, liquid effluents and solid wastes per unit of concrete product developed in this part of the report will therefore comprise the set of unit factors used as input to the Sustainable Materials Project calculation model. Portland cement is one of several materials used in concrete production and the cement unit factors developed in Part I of the report are therefore used in this part with appropriate adjustments to reflect the relative proportions of cement and other raw materials used in making concrete products.

This section sets the stage for the unit factor analysis by presenting a brief overview of the concrete products industry in Canada.

9.1 CONCRETE MANUFACTURING

Concrete is a mixture in which a paste of cement and water binds materials such as coarse aggregate (stone) and fine aggregate (sand) into a rock-like mass. The paste hardens as a result of chemical reactions between the cement and water. Fresh and hardened concrete properties such as workability, setting time, water demand, air entrainment and strength can be modified or adjusted by adding chemical and/or mineral admixtures to the concrete during the process. Also, supplementary cementing materials (SCM) such as fly ash and blast furnace slag can be used to replace some of the cement.

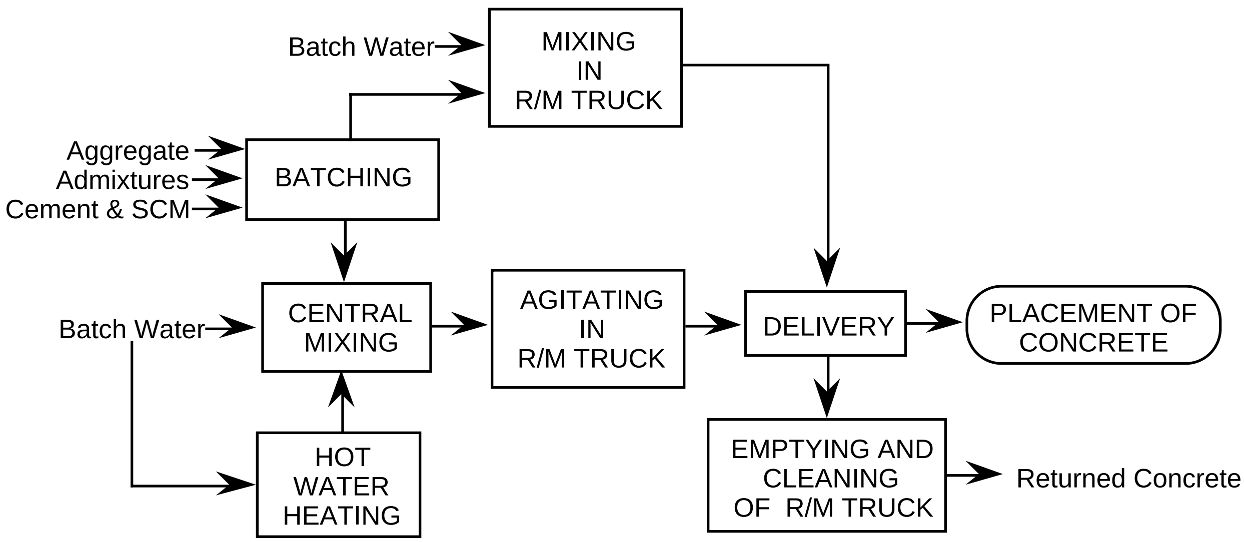
Portland cement accounts for only 9 to 13% of the raw materials used to produce concrete, and concrete is therefore a relatively energy efficient construction material despite the energy intensity of portland cement. The typical proportions of materials used in concrete production are as follows:[1]

Cement	11%
Water	16%
Air	06%
Fine Aggregates	27%
Coarse Aggregates	40%

There are two main concrete product streams of interest from our perspective, ready mixed concrete and precast shapes including concrete blocks. Concrete for both purposes is produced in essentially the same way.

Ready mixed concrete is normally produced by batching stone, sand, cement, SCM and water in the desired proportions by weight, then mixing to an even consistency. As illustrated in Figure 9.1, two manufacturing processes are used — dry batching and wet batching.[2]

Figure 9.1
READY MIXED CONCRETE PRODUCTION



At dry batch plants, portland cement, SCM and fine and coarse aggregate are individually weighed in hoppers and discharged to a ready mixed concrete truck drum. Water and admixtures are metered into the drum and the concrete is mixed in the drum on route to the job site. At wet mix facilities, all of the concrete components are mixed in a central mixer before discharge to the truck drum. The weighing and metering of separate components in both dry and wet batch operations is now largely computerized, resulting in improved quality control.

The process is basically the same at precast plants, but a stationary central mixing facility is used and the concrete is discharged to forms after first positioning any required reinforcing steel. After a suitable curing processes involving time, temperature and humidity control, the product is removed from the forms and stockpiled for finishing and final shipping.

Ready mixed concrete facilities include: permanent plants which use transit mixers to deliver concrete to customers from a central, permanent batch plant; portable plants which are dedicated facilities set up for very large construction projects; and mobile plants which are small facilities used to measure and mix concrete components at a job site.[3]

The three plant types utilize slightly different equipment and operating procedures, and therefore have different waste generation and disposal characteristics. Our focus is on permanent plants which generally have superior wastewater treatment facilities due to their permanency and greater land availability.

9.1.1 Energy Use and Efficiency

Because so little portland cement is used per unit of concrete, concrete production is very energy efficient compared to most other commonly used building products. As discussed in Part I of this report, the energy intensity of cement production has been reduced by about 20% over the past 15 years (Section 2.1.1). The concrete industry has made even greater gains in energy efficiency, reducing the energy required per unit volume of completed construction by at least 50% over the past 20 years.[4]

The reductions in energy use have largely been achieved by reducing the amount of cement used per unit area of concrete construction as a result of:[5]

- improved performance of cement;
- increased use of chemical admixtures;
- increased use of supplementary cementing materials such as blast furnace slag, fly ash and silica fume which are all by-products of other industries requiring relatively little energy for their use;
- improved concrete production quality control which permits a reduced margin for error in developing mixture proportions and therefore allows lower cement content; and
- improved design of concrete structures allowing smaller members to bear loads.

9.1.2 Recycling

As equipment is developed to crush concrete and remove reinforcing steel, both the concrete and the steel can be recycled or reused. In principle, stone-sized and fine particles of concrete can be graded and recycled as aggregates for making new concrete as well as bases for road building.[6] However, there is some debate about adhesion problems associated with using recycling concrete as aggregate for new concrete. Reuse of crushed concrete as road base is a sensible alternative to landfilling or on-site disposal. Although it represents a low value use of crushed concrete, it has the benefit of avoiding the broader environmental impacts of quarrying new aggregate, and is steadily gaining acceptance in the industry.

9.2 INDUSTRY STRUCTURE

There are a large number of concrete production facilities spread across Canada, with the ready mixed concrete part of the industry dominating as indicated in Table 9.1.[7]

Table 9.1
LOCATION OF CONCRETE PLANTS BY TYPE
(no. of plants)

REGION	NUMBER OF PLANTS		
	Ready Mixed	Block	Precast
West Coast*	67	6	6
Prairie**	270	10	15
Central ***	357	61	25
East	221	19	15

Notes: * Includes the Northwest Territories
** Includes Manitoba
*** Ontario only

Ready mixed concrete accounts for about 83% of Canadian cement consumption and ready mixed concrete plants produce about 22.3 million m^3 per year of concrete. Block and precast/prestressed concrete products account for another 5% of cement consumption, while the remaining consumption is spread over a variety of products and uses including concrete pipe, paving stones and mining backfill.[8]

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[1]*The Cement Industry's Contribution to Canada's Green Plan* (Canadian Portland Cement Association, 1991), p. 5.
[2]*Recommended Waste Management Practices for the Ready-Mix Concrete Industry in British Columbia* (Envirochem Services, North Vancouver, B. C.; for Environment Canada Conservation and Protection, Pacific Yukon Region, Regional Manuscript Report MS90-03).
[3]Ross, P. D. and Shepher, R. B., *Overview of the Ready-Mix Concrete Industry in British Columbia* (Water and Waste Management Practices, Regional Program Report 88-03, Environment Canada, Conservation and Protection Pacific and Yukon Region, West Vancouver, B. C.).
[4]Canadian Portland Cement Association, op. cit.
[5]Ibid.
[6]Ibid.
[7]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993), p. 16.
[8]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, December 1992 draft).

10.0 RAW MATERIAL REQUIREMENTS AND TRANSPORTATION

10.1 PRODUCT CHARACTERISTICS

Before describing raw material requirements and transportation for the relevant concrete products, it is useful to briefly describe the specific product characteristics assumed for this study.

We have assumed the following water to cement ratios for the three strengths of ready mixed concrete: 15 MPa = 0.76 water/cement ; 20 MPa = 0.67; and 30 MPa = 0.46.

In the case of concrete blocks, we assume an 8 x 8 x 16 inch (200 x 200 x400 mm) size, with 1.25″ (30 mm) thick walls and 1.00″ (25 mm) thick webs, made with normal weight aggregate (sand and gravel). One cubic metre of concrete will yield 104 blocks of that size with the following characteristics:

Weight of concrete (dry)		1890 kg/m^3
Weight/block	40 lb	18.18 kg
Compressive strength (gross area)	1200 - 1800 psi	8.27 - 12.41 MPa

Cement mortar is assumed to be made with a portland cement/fine aggregate ratio of 1:3 by volume (94:240 by weight) and a water/cement ratio of 0.5 to 0.7.[1] Assuming application to a 3/8″ (9 mm) thickness on blocks sized as indicated above requires 51.05 in^3 (.0008365 m^3) of cement mortar per block, excluding mortar to fill cells.

Typical double T beams are assumed to be 60´ (18.3 m) long by 10´ (3.0 m) wide, with 28″ (0.7 m) stems and require 7.1 cubic yards (5.43 m^3) of 35 MPa concrete per unit, or 0.2969 m^3 of concrete per lineal metre.

Typical hollow deck is assumed to be produced in 8″ (200 mm) thick by 4´ (1.2 m) wide slabs without topping, using 0.17 m^3 of 35 MPa concrete per lineal metre.

10.2 RAW MATERIAL REQUIREMENTS

The raw materials required to produce the relevant concrete products are shown in Table 10.1. There are no regional breakdowns because product formulations are essentially the same in all regions. Regional variations will be introduced in later sections of the report to take account of the differences in energy use and other unit factors in cement as well as in concrete production.

Supplementary cementing materials such as fly ash or granulated blast furnace slag are included in the Table 10.1 ready mixed concrete formulations. There are significant variations in the extent of SCM use across the country, depending on geography and local availability as well as the type of concrete product. Although SCM use in some areas may be as high as 20%, in other areas it is substantially lower. However, no hard data is available on the national use of SCM. Therefore, as suggested by the CPCA, we have adopted the Holderbank estimate of 9% replacement of portland cement in ready mixed concrete.[2] We have not assumed any replacement of cement by SCM in cast products.

Table 10.1
RAW MATERIAL REQUIREMENTS BY CONCRETE PRODUCT
(kg/m^3)

RAW MATERIAL	PRODUCT 15 MPa Ready Mixed	20 MPa Ready Mixed	30 MPa Ready Mixed	Block	Double T Beam	Hollow Deck	Cement Mortar
Cement	191	218	319	189	505	505	307
SCM	19	22	31	0	0	0	0
Coarse Aggregate	970	1009	1092	510	750	750	0
Fine Aggregate	963	925	722	1191	744	744	785
Water	160	160	160	53	202	202	185
Total	2303	2334	2324	1943	2201	2201	1277

SCM - supplementary cementing materials
Sources: Ready mixed - Canadian Portland Cement Association, private correspondence from L. Hamre, P. Eng., Building Science Engineer, November 15, 1993.
Block - J.L Schmidt, H. Bennett and W.H. Lewis, *Construction Principles, Materials and Methods* (ASLIP, Chicago, Ill., 1972).
Double T and hollow deck - same source as for ready mixed.
Cement Mortar - F.M. Lea, *The Chemistry of Cement and Concrete* (Chemical Publishing Company, Inc., New York, 1971), p. 531.

In addition to the materials shown in Table 10.1, double T beams and hollow deck contain reinforcing steel. While not strictly a raw material, the reinforcing steel is a critical manufactured component that has to been taken into account in the Sustainable Materials Project model.

The agreed procedure for ensuring inclusion of such components requires that we estimate the weight of specific steel products used per unit of concrete product. The Sustainable Materials Project model will be structured to then assign energy, emissions and other unit factors to the steel content and to add those factors to the concrete estimates developed here to produce the overall concrete product estimates. The steel unit factor estimates have been developed separately as part of the companion steel study.

Steel requirements for typical versions of the two products have been estimated as follows.[3]

Double T Beams[4]

Twelve 1/2″ (12.5 mm) diameter steel strands are required per 10´ (3.0 m) width, which translates to 1696 $in.^3$ ($12 \times \pi d^2/4 \times 60'$) or 482 lb of steel per beam (1696 x .284 $lb/in.^3$). Converting to metric yields the following estimates of steel reinforcement requirements in volume and linear terms:

482 lb of steel/double T = 40 kg of steel/m^3 of concrete
= 12 kg of steel/m of double T

Hollow Deck[5]

Seven strands of 1/2″ (12.5 mm) diameter are required per 4´ (1.2 m) width of deck, which means 54 $in.^3$ of steel per metre of deck ($7 \times \pi d^2/4$), or 15.4 lb of steel per metre. Converting to metric yields the following steel requirements:

15.4 lb of steel per metre of deck = 7 kg per metre of deck
= 41 kg of steel per m^3 of concrete

10.3 RAW MATERIAL TRANSPORTATION

As noted in Section 9.0, the concrete products industry is widely dispersed with a large number of plants in every region. Coarse and fine aggregate sources are also plentiful across the country and most concrete plants can therefore locate relatively close to sources of the two raw materials. Therefore, although we have no hard information about raw material transportation distances and modes, we believe the following assumptions are reasonable.

For coarse aggregates, we have assumed an average haul distance by truck of 10 kilometres for all plants in all regions. For fine aggregates, we have assumed an average of 15 kilometres by truck for all plants in all regions. Doubling these distances to account for empty backhauls results in assumed truck transportation requirements of 20 kilometres for coarse and 30 kilometres for fine aggregates.

No detailed information is available concerning types, sources of supply and modes of transportation of SCM in different regions. We therefore made the following assumptions for the respective markets based on our experience:

Vancouver	- 80% fly ash, equally split between sources in Alberta and Washington state, transported by rail with local transportation by truck
	- 20% blast furnace slag from Japan by ship, with local transportation by truck
Calgary	- 100% Alberta fly ash, transported by truck
Winnipeg	- 100% local fly ash, transported by truck
Toronto	- 60% fly ash, equally split between sources in upper NY state and Michigan, transported by truck
	- 40% blast furnace slag from Hamilton, transported by truck
Montreal	- 100% fly ash from Nova Scotia, transported by ship, with local transportation by truck
Halifax	- 100% local fly ash, transported by truck

We also have to take account of the transportation of reinforcing steel to precast concrete manufacturing plants. Again, we do not have hard information about plant locations relative to steel production facilities. However, Statistics Canada's report "Trucking in Canada 1985" indicates a typical distance of 346 kilometres from producers of steel rods and bars to suppliers (i.e. distributors). We have adopted that figure without adding for empty backhauls to at least approximate the transportation distance, recognizing that in some parts of the country it may overstate the distance while in others it may understate.

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[1]Cement mortars often have some lime content to improve plasticity. However, the differences between unit factor estimates for a lime mortar and one made only with portland cement would be minimal and we have therefore developed estimates for only the portland cement version.

[2]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993), p. 23.

[3]The Sustainable Materials Project systems model will have the capability of varying the steel requirements in double T beams and hollow deck to accommodate other versions of these products specified in building assemblies.

[4]*CPCI Metric Design Manual, Precast & Prestressed Concrete* (CPCI, Ottawa); and, *PCI Design Handbook*, 4th Edition (PCI, Chicago).

[5]Same source as for Double T beams.

11.0 ENERGY USE

This section presents our estimates of energy use for the concrete products listed previously. The estimates include energy to extract, process and transport the aggregates, to transport and process supplementary cementing materials, and to transport reinforcing steel for precast products. The estimates also include energy embodied in the cement (from Part I of the report), and energy required to finally manufacture the products.

The boundary for this analysis is the plant gate of the concrete production facility. Energy associated with the transportation of ready mixed and other finished concrete products from the plant gate to a construction site is being estimated as part of the building construction component of the Sustainable Materials Project. This approach is consistent with the treatment of wood and steel building products, where final transportation from distribution centres to construction sites is included in the construction stage of activity.

All estimates are presented by region for the six cities identified in Part I (Section 4.3) and are expressed in giga joules per unit of finished product (i.e. GJ per m^3, per block or per metre). Because we assumed cement delivered to each of the cities would be produced in the region where each is located, the weighting used for cement production is implicit in the concrete estimates.

11.1 RAW MATERIAL EXTRACTION, PROCESSING AND TRANSPORTATION

We have assumed the same per tonne energy breakdown for the extraction and processing of coarse and fine aggregates in all regions and for all products. Energy use for these stages of activity differs by final product only as a result of the differences in the amounts of raw materials required to produce each product.

For coarse aggregates, the energy requirements by fuel type for raw material extraction and processing are as follows:

Extraction[1]	Diesel - Road	0.0270 GJ/t
Processing[2]	Electricity	0.0108 GJ/t
Total		0.0378 GJ/t

The same sources provide the following estimates for fine aggregates, assuming fine aggegate production involves quarrying and crushing:

Extraction	Diesel - Road	0.0270 GJ/t
Processing	Electricity	0.0324 GJ/t
Total		0.0594 GJ/t

Using the distance estimates from Section 10.3 and the diesel (road) combustion energy factor of 1.18 MJ per tonne-kilometre yields the following estimates of transportation energy coarse and fine aggregates and reinforcing steel.

Coarse Aggregates	0.0236 GJ/t
Fine Aggregates	0.0354 GJ/t
Reinforcing Steel	0.4083 GJ/t

In the case of supplementary cementing materials, manufacturing energy is not included in this study because SCM are by-products of power generating or steel industries (see Sustainable Materials Project Research Guidelines). Only transportation and processing (grinding) energy is considered where applicable. Also, unlike our assumption for aggregates, the SCM energy use components vary by city.

The following estimates of SCM transportation energy by city are based on the assumptions set out in Section 10.3 and the appropriate diesel road, diesel rail and HFO marine combustion factors per tonne-kilometer.

CITY	Diesel Road Gj/t	Diesel Rail Gj/t	HFO Marine Gj/t	Total Transp. Gj/t
Vancouver	0.05900	0.68600	0.19200	0.93700
Calgary	0.40120	0	0	0.40120
Winnipeg	0.11800	0	0	0.11800
Toronto	0.55224	0	0	0.55224
Montreal	0.05900	0	0.30000	0.35900
Halifax	0.11800	0	0	0.11800

Estimates of weighted average processing energy are based on the assumption that fly ash does not require any processing, whereas granulated blast furnace slag has to be ground. Since it is harder to grind, and is usually ground finer, than portland cement, we assume the energy required is one and a half that of the energy required for finish grinding of portland cement — 1.5 x 0.19495 = 0.29243 GJ/tonne of blast furnace slag (see Table 4.2). Multiplying this figure by the percentage of blast furnace slag in the SCM mix for the relevant cities yields the following electrical energy estimates per tonne of SCM:

Vancouver	0.05849 Gj/t
Toronto	0.11697 Gj/t

Transportation of cement to concrete plants in each of the six cities is included in the total cement energy estimates from Part I of this report (Sections 4.3 and 4.4).

11.2 READY MIXED CONCRETE

Energy use estimates for ready mixed concrete were developed for each stage of activity (i.e. raw material extraction including processing, raw material transportation and manufacturing) as follows:

Raw Material Extraction and Processing

Raw material requirements (aggregates and SCM) in kg/m^3 of concrete from Section 10.2 were multiplied by the energy requirement estimates shown in Section 11.1 above. Following is an example calculation for 15 MPa ready mixed concrete for Vancouver. The same process is used for 20 and 30 MPa ready mixed concrete and for other cities.

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	970		0.0378		0.03667
Fine Aggregate	963		0.0594		0.05720
SCM	19		0.0585		0.00111
			Total		0.09498

Raw Material Transportation

The same approach was used to estimate raw material transportation energy requirements for ready mixed concrete as illustrated in the following example for 15 MPa ready mixed concrete for Vancouver.

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	970		0.0236		0.02289
Fine Aggregate	963		0.0354		0.03409
SCM	19		0.9370		0.01780
			Total		0.07478

Manufacturing

The following manufacturing energy requirements per tonne of ready mixed concrete were taken from Holderbank.[3]

	GJ/t
Electricity	0.0060
Light Fuel Oil	0.0175
Natural Gas	0.0175
Diesel Fuel	0.0630
Total	0.1040

Holderbank cites a total of 35 MJ/t of either natural gas or light fuel oil used in manufacturing, and we have arbitrarily split that estimate on a 50/50 basis to include both fuel types. Since we assume the same manufacturing energy estimates for all six cities, this arbitrary split introduces a slight error in our estimates of energy use by fuel type for Halifax where natural gas is not available. As a consequence, our later estimates of atmospheric emissions for Halifax are slightly understated.

The above estimates of manufacturing energy use per tonne of concrete apply equally to all three strengths of ready mixed concrete, and our final manufacturing estimates reflect a simple multiplication of the total of 0.104 GJ/t by the total weight of the concrete per m^3 (i.e. the total weight of materials from Section 10.2) for each of the three ready mixed concrete formulations.

Tables 11.1, 11.2 and 11.3 summarize the total energy use estimates for 15, 20 and 30 MPa ready mixed concrete, respectively.

Table 11.1
ENERGY USE IN 15 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE (GJ/m^3)

REGION	PROCESS STAGE					TOTAL
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-Total	
West Coast						
Vancouver	0.09498	0.07479	0.94716	0.23951	1.18667	1.35643
Prairie						
Calgary	0.09387	0.06461	0.94528	0.23951	1.18479	1.34326
Winnipeg	0.09387	0.05922	1.11924	0.23951	1.35875	1.51185
Central						
Toronto	0.09609	0.06747	0.89563	0.23951	1.13514	1.29870
East						
Montreal	0.09387	0.06380	1.11536	0.23951	1.35487	1.51254
Halifax	0.09387	0.05922	1.11721	0.23951	1.35672	1.50981

Note: Raw materials are coarse and fine aggregate and SCM, and extraction includes raw material processing.

Table 11.2
ENERGY USE IN 20 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE (GJ/m^3)

REGION	PROCESS STAGE					TOTAL
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-Total	
West Coast						
Vancouver	0.09437	0.07717	1.08105	0.24274	1.32378	1.49533
Prairie						
Calgary	0.09309	0.06538	1.07890	0.24274	1.32164	1.48011
Winnipeg	0.09309	0.05915	1.27746	0.24274	1.52019	1.67243
Central						
Toronto	0.09566	0.06871	1.02223	0.24274	1.26497	1.42934
East						
Montreal	0.09309	0.06446	1.27303	0.24274	1.51576	1.67330
Halifax	0.09309	0.05915	1.27514	0.24274	1.51787	1.67011

Note: Raw materials are coarse and fine aggregate and SCM, and extraction includes raw material processing.

Table 11.3
ENERGY USE IN 30 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE (GJ/m^3)

REGION	PROCESS STAGE					TOTAL
	Raw Material Extraction	Raw Material Transportation	Manufacturing Cement	Manufacturing Processing	Manufacturing Sub-Total	
West Coast						
Vancouver	0.08598	0.08038	1.58190	0.24170	1.82360	1.98995
Prairie						
Calgary	0.08416	0.06377	1.57876	0.24170	1.82046	1.96839
Winnipeg	0.08416	0.05499	1.86931	0.24170	2.11100	2.25016
Central						
Toronto	0.08779	0.06845	1.49584	0.24170	1.73753	1.89377
East						
Montreal	0.08416	0.06246	1.86282	0.24170	2.10452	2.25114
Halifax	0.08416	0.05499	1.86591	0.24170	2.10761	2.24676

Note: Raw materials are coarse and fine aggregate and SCM, and extraction includes raw material processing.

In the above three tables, the energy content of cement is included at the manufacturing stage and accounts for 70 - 85% of the energy embodied in ready mixed concrete products, depending on the city and strength of concrete. The cement estimates, in turn, include all embodied energy for the delivered cement with the breakdown by activity stage provided in Part I of the report.

A good case could be made for distributing the cement energy estimates by process or activity stage across the activity stages for concrete production. That approach has appeal because it would give a better indication of the energy associated with all resource extraction, transportation and manufacturing stages for cement and concrete together. But it would be equivalent to treating the cement and concrete producers as one industry, which they are not. It would also then be more difficult to maintain a distinction between cement and concrete and to show the separate contributions to total energy use of the two industries. The approach we have adopted has the virtue of allowing the cement energy to be easily distinguished and separated from other energy used in concrete production.

The other argument in favour of the approach we have adopted is that the manufacturing stage of cement production accounts for about 95% of the energy in cement and would be added to the concrete manufacturing stage in any event.

Tables 11.4, 11.5 and 11.6 summarize the total energy requirements for the three strengths of ready mixed concrete by fuel type, including the cement energy by fuel type. The underlying breakdowns of these fuel type estimates by process stage are used subsequently to estimate atmospheric emissions, with the cement values continuing to be added at the manufacturing stage of concrete products.

Table 11.4
ENERGY USE IN 15 MPA READY MIXED CONCRETE PRODUCTION BY FUEL TYPE (GJ/m^3)

REGION	ENERGY FORM									TOTAL
	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	
West Coast										
Vancouver	0.2911	0.0131	0.0193	0.4801	0.2795	0.0700	0.0375	0.0000	0.1658	1.3564
Prairie										
Calgary	0.3486	0.0360	0.0000	0.7406	0.0000	0.0403	0.0000	0.0000	0.1778	1.3433
Winnipeg	0.2720	0.2812	0.0000	0.7406	0.0000	0.0403	0.0000	0.0000	0.1778	1.5119
Central										
Toronto	0.3007	0.0011	0.0092	0.1515	0.4333	0.0558	0.1204	0.0509	0.1760	1.2987
East										
Montreal	0.3077	0.0057	0.0072	0.1882	0.3176	0.2023	0.2267	0.0896	0.1675	1.5125
Halifax	0.3094	0.0000	0.0085	0.1882	0.3176	0.2023	0.2267	0.0896	0.1675	1.5098

Note: Totals may not add due to rounding.

Table 11.5
ENERGY USE IN 20 MPA READY MIXED CONCRETE PRODUCTION BY FUEL TYPE (GJ/m^3)

REGION	ENERGY FORM									TOTAL
	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	
West Coast										
Vancouver	0.2979	0.0152	0.0221	0.5429	0.3190	0.0747	0.0428	0.0000	0.1807	1.4953
Prairie										
Calgary	0.3636	0.0411	0.0000	0.8401	0.0000	0.0409	0.0000	0.0000	0.1944	1.4801
Winnipeg	0.2761	0.3210	0.0000	0.8401	0.0000	0.0409	0.0000	0.0000	0.1944	1.6724
Central										
Toronto	0.3090	0.0012	0.0105	0.1677	0.4946	0.0585	0.1375	0.0580	0.1924	1.4293
East										
Montreal	0.3169	0.0065	0.0083	0.2097	0.3625	0.2257	0.2588	0.1023	0.1827	1.6733
Halifax	0.3188	0.0000	0.0097	0.2097	0.3625	0.2257	0.2588	0.1023	0.1827	1.6701

Note: Totals may not add due to rounding.

Table 11.6
ENERGY USE IN 30 MPA READY MIXED CONCRETE PRODUCTION BY FUEL TYPE (GJ/m^3)

REGION	ENERGY FORM									TOTAL
	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	
West Coast										
Vancouver	0.3082	0.0214	0.0321	0.7753	0.4668	0.0903	0.0626	0.0000	0.2333	1.9900
Prairie										
Calgary	0.4040	0.0601	0.0000	1.2103	0.0000	0.0407	0.0000	0.0000	0.2533	1.9684
Winnipeg	0.2762	0.4697	0.0000	1.2103	0.0000	0.0407	0.0000	0.0000	0.2533	2.2502
Central										
Toronto	0.3238	0.0018	0.0153	0.2263	0.7237	0.0665	0.2012	0.0849	0.2502	1.8938
East										
Montreal	0.3360	0.0095	0.0118	0.2877	0.5305	0.3112	0.3787	0.1497	0.2361	2.2511
Halifax	0.3387	0.0000	0.0142	0.2877	0.5305	0.3112	0.3787	0.1497	0.2361	2.2468

Note: Totals may not add due to rounding.

11.3 CONCRETE BLOCKS

Following are the basic calculations for estimating energy use by activity stage for concrete blocks.

Raw Material Extraction and Processing

Raw material requirements in kg/m^3 of concrete from Section 10.2 were multiplied by the energy requirement estimates shown in Section 11.1 above.

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	510		0.0378		0.01928
Fine Aggregate	1191		0.0594		0.07075
				Total	0.09003

Raw Material Transportation

Raw material transportation energy requirements were estimated using the energy per tonne factors from Section 11.1.

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	510		0.0236		0.01204
Fine Aggregate	1191		0.0354		0.04216
			Total		0.05420

Manufacturing

The following manufacturing energy requirements per tonne of ready mixed concrete were taken from Holderbank.[4]

	GJ/t
Electricity	0.0640
Natural Gas	0.4730
Diesel Fuel	0.1270
Total	0.6640

Unlike its treatment of ready mixed concrete, Holderbank does not indicate use of either natural gas or light fuel oil in the manufacture of concrete blocks, double T beams and hollow deck. We have therefore followed Holderbank's lead and cited only the natural gas numbers, even though this is not possible for Halifax. Again, the assumption of natural gas use in Halifax leads to an under-estimate of emissions for that city for all three products.

The above factors were used to develop final energy estimates in GJ/m3 of concrete. Those estimates were then divided by 104 (the number of blocks produced from 1 m^3 of concrete) to derive the energy estimates in GJ/block shown in Table 11.7 below. As in the case of ready mixed concrete, the cement energy is included at the manufacturing stage.

Table 11.7
ENERGY USE IN CONCRETE BLOCK PRODUCTION BY PROCESS STAGE (GJ/block)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.00087	0.00052	0.00901	0.01241	0.02142	0.02281
Prairie						
Calgary	0.00087	0.00052	0.00899	0.01241	0.02140	0.02279
Winnipeg	0.00087	0.00052	0.01065	0.01241	0.02306	0.02445
Central						
Toronto	0.00087	0.00052	0.00852	0.01241	0.02093	0.02232
East						
Montreal	0.00087	0.00052	0.01061	0.01241	0.02302	0.02441
Halifax	0.00087	0.00052	0.01063	0.01241	0.02304	0.02443

Note: Raw materials are coarse and fine aggregate and extraction includes raw material processing.

Table 11.8 shows a breakdown of the above total energy estimates by fuel type.

Table 11.8
ENERGY USE IN CONCRETE BLOCK PRODUCTION BY FUEL TYPE
(GJ/block)

REGION	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	TOTAL
	ENERGY FORM									
West Coast										
Vancouver	0.0037	0.0000	0.0002	0.0130	0.0027	0.0003	0.0004	0.0000	0.0027	0.0228
Prairie										
Calgary	0.0042	0.0003	0.0000	0.0155	0.0000	0.0000	0.0000	0.0000	0.0028	0.0228
Winnipeg	0.0035	0.0027	0.0000	0.0155	0.0000	0.0000	0.0000	0.0000	0.0028	0.0244
Central										
Toronto	0.0037	0.0000	0.0001	0.0099	0.0041	0.0002	0.0012	0.0005	0.0027	0.0223
East										
Montreal	0.0038	0.0001	0.0000	0.0102	0.0030	0.0015	0.0022	0.0009	0.0027	0.0244
Halifax	0.0038	0.0000	0.0001	0.0102	0.0030	0.0015	0.0022	0.0009	0.0027	0.0244

Note: Totals may not add due to rounding.

11.4 CEMENT MORTAR

The full set of energy estimates for cement mortar is included in this report for completeness, as are associated emissions and other unit factors, even though cement mortar is typically made from the raw materials at a construction site and should therefore logically be treated as a construction stage activity.

Following are the calculations for energy to produce cement mortar, by activity stage.

Raw Material Extraction and Processing

Raw Material	Kg/m3 of mortar	x	GJ/1000 kg	=	GJ/m3 of mortar
Fine Aggregate	785		0.0594		0.04663

Raw Material Transportation

Raw Material	Kg/m3 of mortar	x	GJ/1000 kg	=	GJ/m3 of mortar
Fine Aggregate	785		0.0354		0.02779

Manufacturing (Mixing)

The manufacturing stage simply involves mixing the fine aggregate, cement and water. We have assumed a 3 cubic foot (0.085 m^3) mixer driven by a 3/4 HP electric motor, with a mix time of 10 minutes.[5] The following calculations yield the estimate of total electrical energy use per m^3 of mortar.[6]

3/4 HP = 560 W
.560 kWh x 3.6 MJ/kWh = 2.016 MJ
= .336 MJ/mix
= 3.95 MJ/m^3

Tables 11.9 and 11.10 show the cement mortar energy requirements by activity stage and by fuel type, with cement included at the manufacturing stage.

Table 11.9
ENERGY USE IN CEMENT MORTAR PRODUCTION BY PROCESS STAGE
(GJ/m^3)

REGION	PROCESS STAGE					TOTAL
	Raw Material Extraction	Raw Material Transportation	Manufacturing			
			Cement	Processing	Sub-Total	
West Coast						
Vancouver	0.04663	0.02779	1.52239	0.00395	1.52634	1.60076
Prairie						
Calgary	0.04663	0.02779	1.51937	0.00395	1.52332	1.59774
Winnipeg	0.04663	0.02779	1.79899	0.00395	1.80294	1.87736
Central						
Toronto	0.04663	0.02779	1.43957	0.00395	1.44352	1.51794
East						
Montreal	0.04663	0.02779	1.79275	0.00395	1.79670	1.87112
Halifax	0.04663	0.02779	1.79572	0.00395	1.79967	1.87409

Note: The raw material is fine aggregate and extraction includes processing.

Table 11.10
ENERGY USE IN CEMENT MORTAR PRODUCTION BY FUEL TYPE
(GJ/m^3)

REGION	ENERGY FORM									TOTAL
	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	
West Coast										
Vancouver	0.1064	0.0002	0.0252	0.7070	0.4492	0.0477	0.0603	0.0000	0.2048	1.6008
Prairie										
Calgary	0.1884	0.0579	0.0000	1.1256	0.0000	0.0000	0.0000	0.0000	0.2259	1.5977
Winnipeg	0.0739	0.4520	0.0000	1.1256	0.0000	0.0000	0.0000	0.0000	0.2259	1.8774
Central										
Toronto	0.1067	0.0017	0.0147	0.1787	0.6965	0.0249	0.1936	0.0817	0.2194	1.5179
East										
Montreal	0.1331	0.0091	0.0024	0.2377	0.5105	0.2603	0.3644	0.1441	0.2094	1.8711
Halifax	0.1340	0.0000	0.0136	0.2377	0.5105	0.2603	0.3644	0.1441	0.2094	1.8741

Note: Totals may not add due to rounding.

11.5 DOUBLE T BEAMS AND HOLLOW DECK

Typical double T beams and hollow deck are both made from 35 MPa concrete. The manufacturing processes used are essentially the same and, apart from shape and size, the only difference between these products from our perspective is the difference in the amount of reinforcing steel used per unit or per metre (Section 10.2).

Following are the basic calculations by activity stage.

Raw Material Extraction and Processing

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	750		0.0378		0.02835
Fine Aggregate	744		0.0594		0.04419
			Total		0.07254

Raw Material Transportation

Raw Material	Kg/m3 of concrete	x	GJ/1000 kg	=	GJ/m3 of concrete
Coarse Aggregate	750		0.0236		0.01770
Fine Aggregate	744		0.0354		0.02634
Steel for double T	40		0.4083		0.01633
Steel for hollow deck	41		0.4083		0.01674
			Dbl T Total		0.06037
			Deck Total		0.06078

Manufacturing

The energy for handling and mixing concrete and for vibrating the forms is assumed to be the same as for precast concrete pipe. The following estimates were taken from Holderbank.[7]

	GJ/t
Electricity	0.0390
Diesel Fuel	0.0320
Total	0.0710

In addition, energy is required for curing the concrete. The estimates were developed as follows:[8]

curing heat	= 1.02 million BTU/double T
x 1054 J/BTU	= 1,077.12 million J/double T
	= 1.08 GJ/double T

Assuming 60% boiler efficiency, yields an estimate of 1.8 GJ per double T. Dividing by 5.43 m^3 of concrete per double T yields the final estimate of .33149 GJ per m^3 of concrete. The same per m^3 estimate is then applied to hollow deck.

Different plants use different fuels and curing energy is therefore assumed to be provided 2/3 from natural gas and 1/3 from fuel oil, which introduces an additional error in our estimates of emissions for these products for Halifax.

The final energy estimates shown in Tables 11.11 and 11.12 are expressed in GJ per lineal metre of typical double T and Hollow deck. The estimates were first developed in terms of m^3 of concrete and then converted to lineal units using the following factors:

1 lineal metre of double T requires 0.296916 m^3 of concrete; and
1 lineal metre of Hollow deck requires 0.17 m^3 of concrete.

Table 11.11
ENERGY USE IN DOUBLE T BEAM PRODUCTION BY PROCESS STAGE
(GJ/metre of 10' wide beam)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.02154	0.01792	0.74356	0.14483	0.88839	0.92785
Prairie						
Calgary	0.02154	0.01792	0.74208	0.14483	0.88691	0.92637
Winnipeg	0.02154	0.01792	0.87865	0.14483	1.02348	1.06294
Central						
Toronto	0.02154	0.01792	0.70310	0.14483	0.84793	0.88739
East						
Montreal	0.02154	0.01792	0.87560	0.14483	1.02043	1.05989
Halifax	0.02154	0.01792	0.87705	0.14483	1.02188	1.06134

Note: Raw material extraction covers coarse and fine aggregate and includes processing; raw material transportation also includes transportation of reinforcing steel.

Table 11.12
ENERGY USE IN HOLLOW DECK PRODUCTION BY PROCESS STAGE
(GJ/metre of 4' wide by 8" deep slab)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.01233	0.01033	0.42572	0.08292	0.50864	0.53130
Prairie						
Calgary	0.01233	0.01033	0.42488	0.08292	0.50780	0.53046
Winnipeg	0.01233	0.01033	0.50307	0.08292	0.58599	0.60865
Central						
Toronto	0.01233	0.01033	0.40256	0.08292	0.48548	0.50814
East						
Montreal	0.01233	0.01033	0.50133	0.08292	0.58425	0.60691
Halifax	0.01233	0.01033	0.50216	0.08292	0.58508	0.60774

Note: Raw material extraction covers coarse and fine aggregate and includes processing; raw material transportation also includes transportation of reinforcing steel.

Tables 11.13 and 11.14 show breakdowns of the above total energy estimates by fuel type.

Table 11.13
ENERGY USE IN DOUBLE T BEAM PRODUCTION BY FUEL TYPE
(GJ/metre of 10' wide beam)

REGION	ENERGY FORM: Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	TOTAL
West Coast										
Vancouver	0.0788	0.0001	0.0123	0.4109	0.2194	0.0561	0.0294	0.0000	0.1207	0.9277
Prairie										
Calgary	0.1189	0.0283	0.0000	0.6154	0.0000	0.0328	0.0000	0.0000	0.1310	0.9264
Winnipeg	0.0630	0.2208	0.0000	0.6154	0.0000	0.0328	0.0000	0.0000	0.1310	1.0630
Central										
Toronto	0.0790	0.0008	0.0072	0.1529	0.3402	0.0450	0.0946	0.0399	0.1279	0.8875
East										
Montreal	0.0919	0.0045	0.0012	0.1817	0.2494	0.1600	0.1780	0.0704	0.1230	1.0601
Halifax	0.0923	0.0000	0.0067	0.1817	0.2494	0.1600	0.1780	0.0704	0.1230	1.0615

Note: Totals may not add due to rounding.

Table 11.14
ENERGY USE IN HOLLOW DECK PRODUCTION BY FUEL TYPE
(GJ/metre of 4’ wide by 8” deep slab)

	ENERGY FORM									
REGION	Diesel Road	Diesel Rail	HFO Marine	Natural Gas	Coal	Oil	Coke	Waste	Electric	**TOTAL**
West Coast										
Vancouver	0.0451	0.0001	0.0070	0.2353	0.1256	0.0321	0.0169	0.0000	0.0691	0.5312
Prairie										
Calgary	0.0681	0.0162	0.0000	0.3523	0.0000	0.0188	0.0000	0.0000	0.0750	0.5304
Winnipeg	0.0361	0.1264	0.0000	0.3523	0.0000	0.0188	0.0000	0.0000	0.0750	0.6086
Central										
Toronto	0.0452	0.0005	0.0041	0.0875	0.1948	0.0257	0.0541	0.0229	0.0732	0.5080
East										
Montreal	0.0526	0.0026	0.0007	0.1041	0.1428	0.0916	0.1019	0.0403	0.0704	0.6070
Halifax	0.0529	0.0000	0.0038	0.1041	0.1428	0.0916	0.1019	0.0403	0.0704	0.6078

Note: Totals may not add due to rounding.

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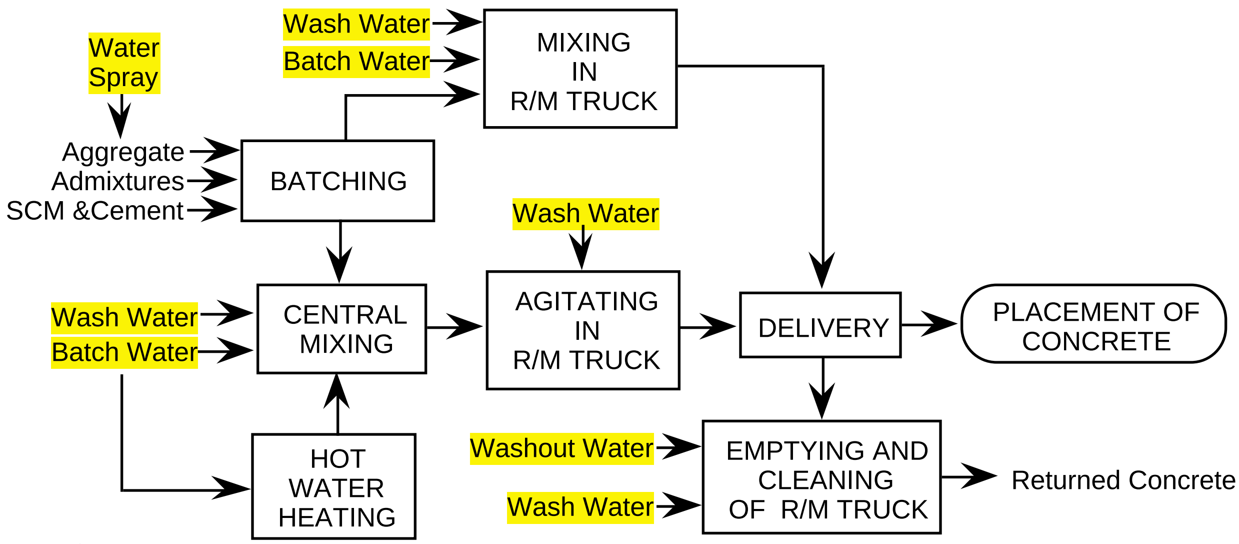
[1]*Canadian Industry program for Energy Conservation (CIPEC)* (Ministry of Energy, Mines and Resources Canada, 1989).
[2]D. Gardner, Y. Chung and LBuja-Bijunas, *An INDEPTH model of Ontario Cement Industry*, (Ontario Hydro, December 1989).
[3]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, December 1992 draft), p. 17 and Appendix 5, p. 3.
[4]Ibid.
[5]Schmidt, J. L., Bennett, H. and Lewis, W. H., *Construction Principles, Materials and Methods* (ASLIP, Chicago, Il., 1972), pp. 205 - 223.
[6]The estimate is based on the theoretical wattage for a motor and understates the actual energy use for a motor under load.
[7]Holderbank, op. cit.
[8]Private communication with Mr. Michael Kraft, VE Service & Engineering Corp., through the courtesy of Mr. John Fowler, CPCI.

12.0 WATER USE

Water is used extensively for concrete production and equipment clean up as illustrated in Figure 12.1, which focuses on water in ready mixed concrete production. Precast concrete plants use less water because the process is more contained and does not require the high volumes of truck washoff and washout water. Nevertheless, the discussion that follows is generally indicative of the industry, given the overall dominance of the ready mixed concrete segment.

Figure 12.1
WATER USE IN READY MIXED CONCRETE PRODUCTION



Specific water uses include concrete batching, central mixer washout, exterior truck washoff, interior truck drum washout and miscellaneous uses such as aggregate moisture control, yard wash-down and product slump adjustment.

Water use varies widely, both daily and from plant to plant, with the volume of consumption depending on daily plant production, the number of operating trucks, the frequency of washoff and washout operations and the volume of miscellaneous water use.

12.1 BATCH WATER

Batch water, the water added to the cement, aggregate and chemical/mineral admixtures to make concrete, typically accounts for the largest volume of water used in concrete production although it may be overshadowed by truck washout requirements in some plants. Potable water has traditionally been used for this purpose, but water of lesser quality may be acceptable if the finished concrete meets acceptable strength, setting time, coloration and shrinkage tests. As a result, the ready mixed concrete industry has been moving toward a zero water discharge approach based on the reuse of wastewater as batch water. However, this approach raises some questions about product quality because contaminants in recycled wash water may adversely affect the appearance and strength characteristics of concrete. One solution may be to increase the cement content, but that approach obviously has cost and other environmental implications.

12.2 TRUCK WASHOUT AND WASHOFF

Truck washouts and washoffs are the other large water using operations in the ready mixed concrete industry, with washouts being the more water intensive of the two.

A mixer truck returning to the plant from a job site may occasionally have unused concrete in the mixing drum. If the concrete is compatible with the next batch, chemical admixtures are available to deactivate the unused concrete and reactivate it the following day for use in the next batch. Returned concrete may also be used to make precast retaining walls or for yard paving. When returned concrete cannot be used, washout water is used to bring the residual concrete in the mixer drum into suspension, in order that it may be flushed out. Recycled water is suitable for this purpose.

Water requirements for a single washout have been estimated to vary from 100 to over 1,000 litres, although we should caution that studies cited in this section are relatively old.[1] Total daily washout water demand is highly variable, depending on the number of operating trucks, the number of central mixers at plants, the washout frequency and the amount of water used per wash. While the first two factors are fixed, the latter two are not.

Washout frequency is determined by the time interval between truck loading, the volume of returned concrete, the characteristics of the preceding batch, housekeeping practices and the ambient temperature. The frequency per truck may vary from once per day to after each load, with the majority of operators washing out only at the end of the day or after a significant mixture change, unless the truck has had a particularly long haul or a long wait. An efficient washout may be accomplished with a single rinse of 950 litres, a double rinse using 375 litres twice for a total of 750 litres or a triple rinse using 190 litres three times for a total of 570 litres.[2]

Truck exteriors are soiled during loading operations, particularly at dry batch plants, and trucks must be washed off to prevent cement build-up on truck drum exteriors and to improve truck appearance during transit. The washoff is usually conducted concurrent with product slump adjustment at dry batch plants and in the loading bay at wet batch plants.

Potable city water is normally used for washoff operations because recycled water may leave a film or residue on the truck exterior as a result of solids concentrations. Recycled water could be used for a preliminary washoff, with clean water used for final rinsing, but this approach is generally inconvenient and only a small percentage of plants use recycled water for washoffs. However, some plants may use clean, but not potable, water from wells or lakes for washoffs and even for batching.

While the frequency of washoffs is constant, the water volume used per washoff is variable and depends on plant housekeeping practices and driver preferences. The average volume has been estimated at 40 litres/truck/washoff. [3]

12.3 MISCELLANEOUS

Miscellaneous water use is highly variable from plant to plant and from day to day. Uses include yard dust control, cement discharge chute rinse-off, and other equipment clean up. Aggregate stockpiles may be sprayed occasionally to maintain a constant moisture content throughout the pile so batch water requirements will be constant for every mix. Most miscellaneous water uses can be accomplished with recycled water.

The miscellaneous use volume requirements have not been comprehensively quantified, but one study estimated it takes about 4,000 litres to wash down a 20-truck facility at the end of each day, which is equivalent to about 200 litres per truck .[4]

12.4 WATER USE SUMMARY

Table 12.1 provides a summary of one estimate of water use in ready mixed concrete production for the above use categories, with the estimates presented in terms of litres of water per cubic metre of concrete.[5]

Table 12.1
ESTIMATED WATER USE IN THE READY MIXED CONCRETE INDUSTRY

Category	Litre/m^3
Batch Water	139 - 188
Truck Washout	15 - 317
Truck Washoff	5 - 69
Miscellaneous	15 - 129
Total	**174 - 703**

There is obviously a large variation in water use from plant to plant and it is difficult to determine average use levels on the basis of available data. What we can say is that figures cited earlier in this section, and in Section 15.2, suggest average water use levels closer to the low end of the above ranges for all but the batch water category. In other words, the distributions within the washout, washoff and miscellaneous ranges may be skewed toward the low ends.

For example, if we assume ready mixed concrete truck loads of 5.2 m^3, an average of 4.2 loads per day, and 1.5 washouts per day (see Section 15.2) using 750 litres per washout, average washout water use would be in the order of 50 litres per cubic metre of concrete. A similar calculation for washoff water suggests an average in the order of 8 litres per cubic metre assuming a washoff after every trip. In the case of the miscellaneous category, use of the 200 litres per truck estimate cited in Section 12.3, above, results in an estimate of only 9 litres per cubic metre — a value less than the low end of the range shown in Table 12.1.

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[1]Meininger, R. C., *Disposal of Truck Mixer Wash Water and Unused Concrete* (National Ready-Mix Concrete Association Publication No. 116, 1964).
[2]Harger, H. L., *A System for 100% Recycling of Returned Concrete: Equipment, Procedures and Effects on Product Quality* (National Ready-Mix Concrete Association Publication No. 150, 1975).
[3]Ibid.
[4]*Guidance Development for Effluent Limitation; Guidelines and New Source Performance Standards for the Concrete Products Point Source Category* (U. S. EPA, 1978).
[5]*Recommended Waste Management Practices for the Ready-Mix Concrete Industry in British Columbia* (Envirochem Services, North Vancouver, B. C.; for Environment Canada Conservation and Protection, Pacific Yukon Region, Regional Manuscript Report MS90-03).

13.0 ATMOSPHERIC EMISSIONS

This section presents the estimates of atmospheric emissions for the concrete products of interest. The first sub-section deals with atmospheric emissions related to the extraction and transportation of raw materials used in all of the concrete products. It should be noted, however, that with the exception of aggregate particulates, the estimates for raw material production and transportation are not used directly in subsequent calculations, and are included here simply to ensure as complete a picture as possible. The second sub-section presents the final atmospheric emission estimates by product and process stage for each city, including a discussion of the approach used to generate the estimates.

With the exception of particulate estimates, which are discussed in the sub-sections that follow, the emissions from concrete production are a combination of the emissions embodied in the cement and the emissions from direct energy use by the concrete industry. Unlike cement, the only process-related emissions from the production of concrete products are particulates. This discussion of atmospheric emissions is therefore more straight forward, and the presentation of results less complex, than the comparable discussion and presentation for cement production emissions in Section 5.0.

13.1 RAW MATERIAL PRODUCTION AND TRANSPORTATION

Non-particulate atmospheric emissions related to aggregate extraction, processing and transportation are a function of energy use. The estimates were therefore developed by applying the fuel-specific emission factors from Table 5.1 to energy use estimates for aggregate extraction, processing and transportation presented in Section 11.1.

For example, the CO_2 emission estimate for the extraction of coarse aggregates is developed as a product of 0.027 GJ/t of diesel fuel use from Section 11.1 and the diesel road emission factor of 70.7 kg/t from Table 5.1. The resulting emission estimate is 1.9089 kg of CO_2 per tonne of aggregate.

The same per tonne energy breakdown is assumed for the extraction, processing and transportation of both fine and coarse aggregates in all of the regions and cities considered in the study (see Section 11.1). The atmospheric emission estimates for aggregate production and transportation are therefore the same for all regions and cities.

A similar approach was used to estimate non-particulate emissions for the transportation of supplementary cementing materials (SCM) and for the processing of blast furnace slag. Fuel-specific emission factors from Table 5.1 were applied to weighted average transportation and processing energy use estimates presented for SCM in Section 11.1.

In the case of particulates, an uncontrolled total particulate matter (TPM) emission factor of 50 g/tonne for both coarse and fine aggregates was taken from Environment Canada.[1] This factor represents total emissions due to aggregate quarrying, crushing, screening, transportation and stockpiling. (The estimate is in agreement with the figure quoted in the AIA Environmental Resource Guide.)[2]

We do not know of any TPM estimates for SCM. However, in the case of fly ash we are only concerned about transportation and particulate emissions from that source would be quite small. In the case of blast furnace slag, some TPM would be generated in processing (grinding), but it is usually well controlled in modern grinding equipment. Moreover, blast furnace slag constitutes only a small fraction of total SCM in only two of the six cities. We have therefore assumed TPM is zero for SCM. We believe the resulting error is negligible considering TPM levels generated in other stages of the process.

Table 13.1 shows the resulting emission estimates for aggregate extraction and transportation. Processing emissions are not included in Table 13.1 because the energy used for processing is in the form of electricity (see Section 11.1) and emissions related to electricity generation are being estimated within the Sustainable Materials Project model as explained in Section 5.1. However, estimates of atmospheric emissions with preliminary electricity-related emissions included are presented in Appendix A in the same manner as for cement emissions. Appendix Table A.7 corresponds to Table 13.1.

Table 13.1
ATMOSPHERIC EMISSIONS DUE TO FINE AND COARSE AGGREGATES

	CO_2 [kg/t]	SO_2 [g/t]	NO_X [g/t]	VOC [g/t]	CH_4 [g/t]	CO [g/t]	TPM [g/t]
Extraction							
Coarse Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Fine Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Transportation							
Coarse Aggregate	1.6685	2.4072	19.0452	2.0508	0.5121	10.4548	
Fine Aggregate	2.5028	3.6108	28.5678	3.0763	0.7682	15.6822	
Total							
Coarse Aggregate	3.5774	5.1612	40.8342	4.3971	1.0980	22.4158	50.0000
Fine Aggregate	4.4117	6.3648	50.3568	5.4226	1.3541	27.6432	50.0000

Table 13.2 shows the emission estimates for SCM transportation and Table A.8 presents the corresponding estimates with electricity-related emissions included.

Table 13.2
ATMOSPHERIC EMISSIONS DUE TO SCM TRANSPORTATION

City	CO_2 [kg/tonne]	SO_2 [g/tonne]	NOx [g/tonne]	VOC [g/tonne]	CH_4 [g/tonne]	CO [g/tonne]
Vancouver	66.8795	162.3900	1046.4130	122.2671	14.3111	66.6598
Calgary	28.3648	40.9224	323.7684	34.8643	8.7060	177.7316
Winnipeg	8.3426	12.0360	95.2260	10.2542	2.5606	52.2740
Toronto	39.0434	56.3285	445.6577	47.9897	11.9836	244.6423
Montreal	26.3713	141.0180	107.6130	113.1271	13.2803	28.3570
Halifax	8.3426	12.0360	95.2260	10.2542	2.5606	52.2740

13.2 EMISSION ESTIMATES BY PRODUCT

The atmospheric emissions estimates were developed for each of the concrete products using the following procedure.

1. The component of total emissions that results from the direct use of energy at each process stage (i.e. aggregate extraction, aggregate and SCM transportation and concrete processing) was estimated by multiplying the energy use estimates by process stage and fuel type (discussed in Section 11.0) by the appropriate emission factors from Table 5.1. For each product, energy estimates related to aggregates production and transportation were assumed to be the same for all cities, while SCM

transportation energy varies by city.

In the case of double T beams and hollow deck, emissions associated with the transportation of reinforcing steel are included at the raw material transportation stage of production.

2. The component of total emissions resulting from the use of cement in individual concrete products was estimated by multiplying cement atmospheric emissions estimates for the relevant city (from Section 5.0) by the cement content factor for each product shown in Table 10.1.

   For example, 191 kg of cement is used per m^3 of 15 MPa ready mixed concrete (from Table 10.1). Cement delivered in Vancouver embodies 271.62 grams of CO per tonne (from Table 5.11). Therefore, CO emissions resulting from the use of cement in the production of 15 MPa ready mixed concrete in Vancouver = 271.62 x .191 = 51.88 grams per m^3.

3. The estimates from steps 1 and 2, above, were added to derive the emission estimates by process stage and city for each product, with the cement-related emissions always added at the manufacturing stage as discussed in Section 11.2.

4. TPM estimates were developed in three steps.

   a) The TPM estimates from Table 13.1 for coarse and fine aggregates were adjusted to reflect the amount of aggregate in each product (e.g. 1.933 tonnes of fine plus coarse aggregate per m^3 of 15 MPa ready mixed concrete (from Table 10.1) x 50 grams per tonne of TPM (from Table 13.1) = 96.65 grams of TPM per m^3 of 15 MPa ready mixed concrete. This component of the total TPM estimate was attributed to the raw material extraction and processing stage for each concrete product.

   b) An additional estimate of 120 grams of TPM per m^3 of concrete was taken from Environment Canada to cover releases during the concrete products manufacturing stage.[3] Our understanding of the estimates is that these TPM releases result from materials handling and mixing and that they do not vary significantly by product.

   c) The TPM estimates for cement (from Table 5.11) were factored to reflect the amount of cement in each product as illustrated in point 2, above. This component of TPM varies by city. The estimates were added to the TPM component from Step 4 (b) to derive the total concrete products manufacturing stage estimate of TPM for each city.

5. Finally, the emission estimates for concrete blocks, double T beams and hollow deck were first derived in terms of m^3 of concrete, and then converted to estimates per block and per lineal metre using the conversion factors cited in Sections 11.3 and 11.5.

The final estimates of atmospheric emissions are shown for each product in Tables 13.3 through 13.9 by process stage and city. Comparable tables with preliminary electricity-related emissions added are presented in Appendix A, Table A.9 through A.15.

Table 13.3
ATMOSPHERIC EMISSIONS DUE TO 15 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Prairies	Calgary	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
	Winnipeg	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Central	Toronto	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
East	Montreal	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
	Halifax	3689.90	5.32	42.12	4.54	1.13	23.12	96.65
Raw Material Transportation								
West Coast	Vancouver	5299.35	8.90	65.87	7.27	1.51	26.51	
Prairies	Calgary	4567.57	6.59	52.14	5.61	1.40	28.62	
	Winnipeg	4187.15	6.04	47.79	5.15	1.29	26.24	
Central	Toronto	4770.47	6.88	54.45	5.86	1.46	29.89	
East	Montreal	4529.70	8.49	48.03	7.10	1.49	25.78	
	Halifax	4187.15	6.04	47.79	5.15	1.29	26.24	
Concrete Processing								
West Coast	Vancouver	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Prairies	Calgary	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
	Winnipeg	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Central	Toronto	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
East	Montreal	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
	Halifax	15206.94	19.76	121.96	12.68	3.21	65.50	120.00
Cement Production								
West Coast	Vancouver	152511.13	18.12	881.55	9.84	2.17	51.88	253.28
Prairies	Calgary	138664.28	12.53	1156.06	10.90	3.07	50.55	339.88
	Winnipeg	150957.78	30.27	1441.79	21.86	3.44	32.93	339.88
Central	Toronto	156895.96	27.84	349.72	7.56	1.66	68.38	225.63
East	Montreal	171378.80	43.27	598.68	7.03	1.95	77.02	324.21
	Halifax	171535.72	45.89	592.62	9.19	2.20	77.02	274.69
Processing Sub-total								
West Coast	Vancouver	167718.07	37.88	1003.51	22.52	5.38	117.38	373.28
Prairies	Calgary	153871.22	32.29	1278.02	23.58	6.28	116.05	459.88
	Winnipeg	166164.72	50.02	1563.75	34.54	6.65	98.43	459.88
Central	Toronto	172102.90	47.59	471.68	20.24	4.87	133.88	345.63
East	Montreal	186585.74	63.03	720.64	19.71	5.16	142.52	444.21
	Halifax	186742.66	65.64	714.58	21.87	5.40	142.52	394.69
TOTAL								
West Coast	Vancouver	176707.33	52.10	1111.50	34.33	8.02	167.01	469.93
Prairies	Calgary	162128.70	44.20	1372.27	33.73	8.81	167.79	556.53
	Winnipeg	174041.78	61.39	1653.66	44.23	9.06	147.79	556.53
Central	Toronto	180563.27	59.80	568.25	30.64	7.47	186.89	442.28
East	Montreal	194805.34	76.84	810.79	31.35	7.78	191.43	540.86
	Halifax	194619.71	77.01	804.49	31.56	7.82	191.88	491.34

Table 13.4
ATMOSPHERIC EMISSIONS DUE TO 20 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Prairie	Calgary	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Winnipeg	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Central	Toronto	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
East	Montreal	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
	Halifax	3691.81	5.33	42.14	4.54	1.13	23.13	96.70
Raw Material Transportation								
West Coast	Vancouver	5094.72	8.80	64.38	7.14	1.43	24.17	
Prairie	Calgary	4247.40	6.13	48.48	5.22	1.30	26.61	
	Winnipeg	3806.91	5.49	43.45	4.68	1.17	23.85	
Central	Toronto	4482.33	6.47	51.16	5.51	1.38	28.09	
East	Montreal	4203.54	8.33	43.73	6.94	1.40	23.33	
	Halifax	3806.91	5.49	43.45	4.68	1.17	23.85	
Concrete Processing								
West Coast	Vancouver	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Prairie	Calgary	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Winnipeg	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Central	Toronto	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
East	Montreal	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
	Halifax	15411.64	20.02	123.61	12.85	3.25	66.39	120.00
Cement Production								
West Coast	Vancouver	174070.30	20.68	1006.17	11.23	2.47	59.21	289.09
Prairie	Calgary	158266.04	14.30	1319.48	12.44	3.51	57.69	387.93
	Winnipeg	172297.36	34.54	1645.60	24.95	3.92	37.58	387.93
Central	Toronto	179074.97	31.77	399.16	8.62	1.90	78.04	257.53
East	Montreal	195605.12	49.39	683.31	8.03	2.23	87.91	370.04
	Halifax	195784.23	52.37	676.39	10.49	2.51	87.91	313.52
Processing Sub-total								
West Coast	Vancouver	189481.93	40.70	1129.77	24.08	5.72	125.60	507.93
Prairie	Calgary	173677.68	34.32	1443.08	25.29	6.76	124.08	507.93
	Winnipeg	187709.00	54.57	1769.20	37.81	7.17	103.97	377.53
Central	Toronto	194486.61	51.80	522.76	21.48	5.15	144.43	490.04
East	Montreal	211016.76	69.41	806.92	20.88	5.48	154.29	433.52
	Halifax	211195.86	72.39	800.00	23.34	5.76	154.29	
TOTAL								
West Coast	Vancouver	196797.12	51.26	1213.27	33.07	7.97	171.43	505.79
Prairie	Calgary	180992.86	44.88	1526.58	34.28	9.00	169.91	604.63
	Winnipeg	195024.19	65.12	1852.70	46.80	9.42	149.80	604.63
Central	Toronto	201801.80	62.35	606.26	30.47	7.39	190.26	474.23
East	Montreal	218331.95	79.96	890.41	29.87	7.72	200.13	586.74
	Halifax	218511.05	82.95	883.49	32.34	8.00	200.13	530.22

Table 13.5
ATMOSPHERIC EMISSIONS DUE TO 30 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Prairie	Calgary	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Winnipeg	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Central	Toronto	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
East	Montreal	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
	Halifax	3462.74	5.00	39.53	4.26	1.06	21.70	90.70
Raw Material Transportation								
West Coast	Vancouver	5501.51	9.98	71.57	8.00	1.50	23.55	
Prairie	Calgary	4307.55	6.21	49.17	5.29	1.32	26.99	
	Winnipeg	3686.86	5.32	42.08	4.53	1.13	23.10	
Central	Toronto	4638.59	6.69	52.95	5.70	1.42	29.06	
East	Montreal	4245.75	9.32	42.47	7.72	1.46	22.36	
	Halifax	3686.86	5.32	42.08	4.53	1.13	23.10	
Concrete Processing								
West Coast	Vancouver	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Prairie	Calgary	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Winnipeg	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Central	Toronto	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
East	Montreal	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
	Halifax	15345.60	19.94	123.08	12.80	3.24	66.10	120.00
Cement Production								
West Coast	Vancouver	254717.54	30.26	1472.33	16.43	3.62	86.65	423.02
Prairie	Calgary	231591.13	20.93	1930.80	18.20	5.13	84.42	567.66
	Winnipeg	252123.21	50.55	2408.01	36.52	5.74	54.99	567.66
Central	Toronto	262040.90	46.49	584.09	12.62	2.78	114.20	376.84
East	Montreal	286229.52	72.27	999.89	11.75	3.26	128.63	541.48
	Halifax	286491.60	76.64	989.76	15.35	3.67	128.64	458.78
Processing Sub-total								
West Coast	Vancouver	270063.15	50.20	1595.40	29.22	6.86	152.75	543.02
Prairie	Calgary	246936.74	40.86	2053.87	31.00	8.37	150.52	687.66
	Winnipeg	267468.81	70.49	2531.09	49.31	8.98	121.09	687.66
Central	Toronto	277386.51	66.43	707.16	25.42	6.02	180.30	496.84
East	Montreal	301575.12	92.21	1122.97	24.54	6.49	194.73	661.48
	Halifax	301837.20	96.57	1112.84	28.15	6.91	194.74	578.78
TOTAL								
West Coast	Vancouver	276954.14	60.14	1674.06	37.69	8.97	195.93	633.72
Prairie	Calgary	253827.72	50.80	2132.53	39.47	10.48	193.70	778.36
	Winnipeg	274359.80	80.43	2609.74	57.78	11.09	164.27	778.36
Central	Toronto	284277.49	76.37	785.82	33.89	8.13	223.48	587.54
East	Montreal	308466.11	102.15	1201.62	33.01	8.61	237.91	752.18
	Halifax	308728.19	106.51	1191.50	36.62	9.02	237.92	669.48

Table 13.6
ATMOSPHERIC EMISSIONS DUE TO CONCRETE BLOCK PRODUCTION
BY PROCESS STAGE AND REGION
(grams/block)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Prairie	Calgary	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Winnipeg	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Central	Toronto	31.22	0.05	0.36	0.04	0.01	0.20	0.82
East	Montreal	31.22	0.05	0.36	0.04	0.01	0.20	0.82
	Halifax	31.22	0.05	0.36	0.04	0.01	0.20	0.82
Raw Material Transportation								
West Coast	Vancouver	36.76	0.05	0.42	0.05	0.01	0.23	
Prairie	Calgary	36.76	0.05	0.42	0.05	0.01	0.23	
	Winnipeg	36.76	0.05	0.42	0.05	0.01	0.23	
Central	Toronto	36.76	0.05	0.42	0.05	0.01	0.23	
East	Montreal	36.76	0.05	0.42	0.05	0.01	0.23	
	Halifax	36.76	0.05	0.42	0.05	0.01	0.23	
Concrete Processing								
West Coast	Vancouver	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Prairie	Calgary	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Winnipeg	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Central	Toronto	606.94	0.24	2.44	0.22	0.06	1.18	1.15
East	Montreal	606.94	0.24	2.44	0.22	0.06	1.18	1.15
	Halifax	606.94	0.24	2.44	0.22	0.06	1.18	1.15
Cement Production								
West Coast	Vancouver	1451.09	0.17	8.39	0.09	0.02	0.49	2.41
Prairie	Calgary	1319.34	0.12	11.00	0.10	0.03	0.48	3.23
	Winnipeg	1436.31	0.29	13.72	0.21	0.03	0.31	3.23
Central	Toronto	1492.81	0.26	3.33	0.07	0.02	0.65	2.15
East	Montreal	1630.61	0.41	5.70	0.07	0.02	0.73	3.08
	Halifax	1632.10	0.44	5.64	0.09	0.02	0.73	2.61
Processing Sub-total								
West Coast	Vancouver	2058.04	0.42	10.82	0.31	0.08	1.68	3.56
Prairie	Calgary	1926.29	0.36	13.44	0.32	0.09	1.66	4.38
	Winnipeg	2043.26	0.53	16.15	0.42	0.10	1.50	4.38
Central	Toronto	2099.76	0.51	5.76	0.29	0.08	1.83	3.30
East	Montreal	2237.56	0.66	8.13	0.28	0.08	1.92	4.23
	Halifax	2239.05	0.68	8.07	0.30	0.08	1.92	3.76
TOTAL								
West Coast	Vancouver	2126.02	0.51	11.60	0.39	0.10	2.10	4.38
Prairie	Calgary	1994.27	0.46	14.21	0.40	0.11	2.09	5.20
	Winnipeg	2111.24	0.63	16.93	0.51	0.12	1.92	5.20
Central	Toronto	2167.74	0.61	6.54	0.37	0.10	2.26	4.12
East	Montreal	2305.54	0.75	8.91	0.37	0.10	2.34	5.05
	Halifax	2307.03	0.78	8.85	0.39	0.10	2.34	4.58

Table 13.7
ATMOSPHERIC EMISSIONS DUE TO CEMENT MORTAR PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Prairie	Calgary	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Winnipeg	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Central	Toronto	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
East	Montreal	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
	Halifax	1498.49	2.16	17.10	1.84	0.46	9.39	39.25
Raw Material Transportation								
West Coast	Vancouver	1964.68	2.83	22.43	2.41	0.60	12.31	
Prairie	Calgary	1964.68	2.83	22.43	2.41	0.60	12.31	
	Winnipeg	1964.68	2.83	22.43	2.41	0.60	12.31	
Central	Toronto	1964.68	2.83	22.43	2.41	0.60	12.31	
East	Montreal	1964.68	2.83	22.43	2.41	0.60	12.31	
	Halifax	1964.68	2.83	22.43	2.41	0.60	12.31	
Concrete Processing								
West Coast	Vancouver	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Prairie	Calgary	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Winnipeg	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Central	Toronto	0.00	0.00	0.00	0.00	0.00	0.00	120.00
East	Montreal	0.00	0.00	0.00	0.00	0.00	0.00	120.00
	Halifax	0.00	0.00	0.00	0.00	0.00	0.00	120.00
Cement Production								
West Coast	Vancouver	245135.69	29.13	1416.94	15.81	3.49	83.39	407.11
Prairie	Calgary	222879.24	20.14	1858.16	17.52	4.94	81.24	546.31
	Winnipeg	242638.95	48.65	2317.43	35.14	5.53	52.92	546.31
Central	Toronto	252183.56	44.75	562.12	12.14	2.67	109.90	362.66
East	Montreal	275462.26	69.55	962.28	11.30	3.13	123.80	521.11
	Halifax	275714.48	73.75	952.53	14.78	3.53	123.80	441.52
Processing Sub-total								
West Coast	Vancouver	245135.69	29.13	1416.94	15.81	3.49	83.39	527.11
Prairie	Calgary	222879.24	20.14	1858.16	17.52	4.94	81.24	666.31
	Winnipeg	242638.95	48.65	2317.43	35.14	5.53	52.92	666.31
Central	Toronto	252183.56	44.75	562.12	12.14	2.67	109.90	482.66
East	Montreal	275462.26	69.55	962.28	11.30	3.13	123.80	641.11
	Halifax	275714.48	73.75	952.53	14.78	3.53	123.80	561.52
TOTAL								
West Coast	Vancouver	248598.86	34.12	1456.47	20.07	4.55	105.09	566.36
Prairie	Calgary	226342.41	25.14	1897.69	21.77	6.00	102.94	705.56
	Winnipeg	246102.12	53.64	2356.96	39.40	6.59	74.62	705.56
Central	Toronto	255646.73	49.74	601.65	16.40	3.74	131.60	521.91
East	Montreal	278925.43	74.55	1001.81	15.56	4.20	145.50	680.36
	Halifax	279177.65	78.75	992.06	19.03	4.59	145.50	600.77

Table 13.8
ATMOSPHERIC EMISSIONS DUE TO DOUBLE T BEAM PRODUCTION BY PROCESS STAGE AND REGION
(grams/metre of 10´ wide beam)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	846.77	1.22	9.67	1.04	0.26	5.31	22.19
Prairie	Calgary	846.77	1.22	9.67	1.04	0.26	5.31	22.19
	Winnipeg	846.77	1.22	9.67	1.04	0.26	5.31	22.19
Central	Toronto	846.77	1.22	9.67	1.04	0.26	5.31	22.19
East	Montreal	846.77	1.22	9.67	1.04	0.26	5.31	22.19
	Halifax	846.77	1.22	9.67	1.04	0.26	5.31	22.19
Raw Material and Steel Transportation								
West Coast	Vancouver	1267.28	1.83	14.47	1.56	0.39	7.94	
Prairie	Calgary	1267.28	1.83	14.47	1.56	0.39	7.94	
	Winnipeg	1267.28	1.83	14.47	1.56	0.39	7.94	
Central	Toronto	1267.28	1.83	14.47	1.56	0.39	7.94	
East	Montreal	1267.28	1.83	14.47	1.56	0.39	7.94	
	Halifax	1267.28	1.83	14.47	1.56	0.39	7.94	
Concrete Processing								
West Coast	Vancouver	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
Prairie	Calgary	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
	Winnipeg	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
Central	Toronto	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
East	Montreal	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
	Halifax	6370.21	2.15	22.68	1.94	0.58	10.74	35.64
Cement Production								
West Coast	Vancouver	119727.29	14.23	692.05	7.72	1.70	40.73	198.84
Prairie	Calgary	108856.97	9.84	907.55	8.56	2.41	39.68	266.82
	Winnipeg	118507.85	23.76	1131.86	17.16	2.70	25.85	266.82
Central	Toronto	123169.56	21.85	274.54	5.93	1.31	53.68	177.13
East	Montreal	134539.16	33.97	469.99	5.52	1.53	60.46	254.52
	Halifax	134662.35	36.02	465.23	7.22	1.72	60.46	215.64
Processing Sub-total								
West Coast	Vancouver	126097.50	16.38	714.74	9.66	2.28	51.47	234.48
Prairie	Calgary	115227.18	11.99	930.23	10.49	2.99	50.42	302.46
	Winnipeg	124878.06	25.91	1154.54	19.10	3.28	36.59	302.46
Central	Toronto	129539.77	24.01	297.23	7.87	1.89	64.42	212.77
East	Montreal	140909.37	36.12	492.67	7.46	2.11	71.20	290.16
	Halifax	141032.56	38.18	487.91	9.15	2.31	71.20	251.28
TOTAL								
West Coast	Vancouver	128211.56	19.43	738.87	12.26	2.93	64.71	256.67
Prairie	Calgary	117341.24	15.04	954.36	13.09	3.64	63.67	324.65
	Winnipeg	126992.12	28.96	1178.67	21.70	3.93	49.84	324.65
Central	Toronto	131653.83	27.06	321.36	10.47	2.54	77.66	234.96
East	Montreal	143023.43	39.17	516.80	10.05	2.76	84.45	312.35
	Halifax	143146.62	41.23	512.04	11.75	2.96	84.45	273.47

Table 13.9
ATMOSPHERIC EMISSIONS DUE TO HOLLOW DECK PRODUCTION BY PROCESS STAGE AND REGION
(grams/metre of 4´ wide by 8¨ deep slab)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Raw Material Extraction and Processing								
West Coast	Vancouver	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Prairie	Calgary	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Winnipeg	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Central	Toronto	484.82	0.70	5.53	0.60	0.15	3.04	12.70
East	Montreal	484.82	0.70	5.53	0.60	0.15	3.04	12.70
	Halifax	484.82	0.70	5.53	0.60	0.15	3.04	12.70
Raw Material and Steel Transportation								
West Coast	Vancouver	730.51	1.05	8.34	0.90	0.22	4.58	
Prairie	Calgary	730.51	1.05	8.34	0.90	0.22	4.58	
	Winnipeg	730.51	1.05	8.34	0.90	0.22	4.58	
Central	Toronto	730.51	1.05	8.34	0.90	0.22	4.58	
East	Montreal	730.51	1.05	8.34	0.90	0.22	4.58	
	Halifax	730.51	1.05	8.34	0.90	0.22	4.58	
Concrete Processing								
West Coast	Vancouver	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Prairie	Calgary	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Winnipeg	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Central	Toronto	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
East	Montreal	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
	Halifax	3647.28	1.23	12.99	1.11	0.33	6.15	20.40
Cement Production								
West Coast	Vancouver	68550.16	8.14	396.24	4.42	0.97	23.32	113.84
Prairie	Calgary	62326.33	5.63	519.62	4.90	1.38	22.72	152.77
	Winnipeg	67851.97	13.60	648.05	9.83	1.55	14.80	152.77
Central	Toronto	70521.04	12.51	157.19	3.40	0.75	30.73	101.42
East	Montreal	77030.73	19.45	269.09	3.16	0.88	34.62	145.72
	Halifax	77101.26	20.62	266.37	4.13	0.99	34.62	123.47
Processing Sub-total								
West Coast	Vancouver	72197.44	9.38	409.22	5.53	1.31	29.47	134.24
Prairie	Calgary	65973.61	6.86	532.61	6.01	1.71	28.87	173.17
	Winnipeg	71499.25	14.84	661.04	10.94	1.88	20.95	173.17
Central	Toronto	74168.32	13.75	170.18	4.50	1.08	36.88	121.82
East	Montreal	80678.01	20.68	282.08	4.27	1.21	40.77	166.12
	Halifax	80748.55	21.86	279.35	5.24	1.32	40.77	143.87
TOTAL								
West Coast	Vancouver	73412.78	11.13	423.10	7.02	1.68	37.08	146.94
Prairie	Calgary	67188.95	8.62	546.48	7.50	2.09	36.48	185.87
	Winnipeg	72714.58	16.59	674.91	12.43	2.25	28.56	185.87
Central	Toronto	75383.66	15.50	184.05	6.00	1.45	44.50	134.52
East	Montreal	81893.35	22.44	295.95	5.76	1.58	48.38	178.82
	Halifax	81963.88	23.61	293.23	6.73	1.69	48.38	156.57

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[1] *A Nationwide Inventory of Emissions of Air Contaminants* (Environment Canada Report EPS 3-EP 23 - 10, Ottawa, December 1983), p. 22.
[2] *Environmental Resource Guide*, *Topic I-3110 4* (The American Institute of Architects, Washington, DC, October 1992).
[3] Environment Canada, op. cit., p. 36.

14.0 LIQUID EFFLUENTS

Water is one of the basic components of any concrete product, constituting up to about 7% by weight of the total raw materials in ready mixed concrete, and about 9% by weight in the precast products examined in this study. Water therefore plays a direct role in concrete production. In addition, water is used extensively in concrete operations for housekeeping and equipment clean up as discussed in Section 12.0.

Most concrete operations use settling ponds to separate suspended solids from collected washoff and washout water. This water is typically recycled back into the operation. The concrete industry as a whole is moving toward "zero discharge" water management, using some wastewater as a part of the batch water, although the approach is not without controversy.[1]

Effluents from the following three sources were combined to estimate total liquid effluents associated with concrete production:

- effluents from cement production;
- effluent from aggregate production; and
- effluent from concrete manufacturing.

Liquid effluents from cement production were discussed in Section 6.0. The estimates presented in Tables 6.1 and 6.2 are used here with adjustments to reflect the amount of cement used in the formulations of each of the concrete products of interest. The next two subsections discuss effluents from aggregate and concrete manufacturing, and the final subsection combines the estimates for all three sources.

14.1 AGGREGATE PRODUCTION

Very little information is available concerning liquid effluents produced by the mineral aggregates industry. One might assume that effluents from aggregate quarries would be somewhat similar to those from cement raw materials quarries. However, there are two important differences.

1. In contrast to cement raw materials, aggregates for use in concrete frequently have to be washed before use (cement raw materials are used as quarried)

2. Suspended solids from aggregate quarries tend to be larger than those from cement raw material quarries, resulting in faster settling rates.[2]

The main concerns about effluents from aggregate quarries are similar to those for cement raw material quarries: namely, the pH of the effluent and of suspended solids, and the amount of oil and grease from mechanical equipment.

The only effluent estimates available were again obtained through the courtesy of the Water Resources Branch of the Ontario Ministry of Environment.[3] It was stressed that the Ministry does not normally monitor the aggregate industry, and that only a few quarries were sampled to obtain some preliminary information. The average aggregate quarry effluents shown in Table 14.1 were developed on the basis of this limited data.

Table 14.1
LIQUID EFFLUENT DUE TO THE PRODUCTION OF AGGREGATE

	Units	Average	Range
pH		7.85	7.4–8.3
Suspended Solids	[mg/L of effluent]	8.68	4.24–12.60
Oil and Grease	[mg/L of effluent]	0.97	0.0–2.9
Flow	[m^3/day]	1016	40–2880

It should be noted that no data were available for the total aggregate output of the monitored quarries, and the estimates developed here are therefore simple rather than weighted averages. It should also be mentioned that one, but only one, out of eight quarries for which information was available, also had some ammonia present in its effluent at 0.49 mg/L of effluent.

Comparing the above aggregate effluent values with those shown in Table 6.2 for cement raw materials quarries, it is apparent that the above levels of suspended solids are an order of magnitude lower. This reflects the difference in particle size noted earlier: a larger portion of the solids in the effluent from aggregate quarries tends to settle rather than staying suspended in the water.

14.2 CONCRETE MANUFACTURING

As discussed in Section 12.0, there is a trend in the concrete industry to move toward zero water discharge by reusing wastewater, not only for the equipment washoff and washout, but also in production batch water. But the only relevant information on wastewater in the ready mixed concrete industry was found in two interrelated studies conducted by or for Environment Canada, Pacific and Yukon Region.[4] In these studies, it was noted that:

> "…in the context of all industrial facilities, ready mix concrete plants do not generally pose significant problems in terms of their environmental impacts. However, concerns may exist at specific facilities, especially where effluent or stormwater runoff is discharged into a water body."

There are three specific environmental concerns regarding effluents from ready mixed concrete facilities:

- *pH:* High pH is toxic to fish. A pH of 9.0–9.5 is likely harmful to salmonid fish, and a pH >10 will kill salmonid fish in minutes.

- *Total suspended solids (TSS):* High TSS is harmful to fish, contributes to oxygen depletion, may contain leachable toxic substances, and can destroy habitat.

- *Oil and grease:* Oil and grease in effluents typically arises from mechanical equipment and is toxic to aquatic organisms. The level of concern is highly variable with species. Crude oil, for example, is extremely toxic at 0.3 mg/L.

In British Columbia, ready mixed concrete facilities are generally regulated by the B.C. Ministry of the Environment, Waste Management Branch. Permits and their specific terms with respect to regulated parameters are determined on a case-by-case basis, but typical requirements are as those shown in Table 14.2.

Table 14.2
TYPICAL READY MIXED CONCRETE EFFLUENT PERMIT REQUIREMENTS IN BRITISH COLUMBIA

Total Suspended Solids (TSS)	50–125 mg/L
pH	6–10
Temperature	< 25–32°C
Oil / Grease	< 5–10 mg/L
Toxicity	96 hour LC_{50} = 100%

Source: *Recommended Waste Management Practices for the Ready Mix Concrete Industry in British Columbia* (Environment Canada, Pacific & Yukon Region, Regional Manuscript Report MS90-03, prepared by Envirochem Services, March 1990).
Note: 96-hour LC_{50} static bioassay on salmonid species expressed as % by volume of effluent in receiving water which is required to give 50% survival over 96 hours.

The specifications shown in Table 14.2 are generally applied to facilities that discharge wastewater effluent to bodies of water. Where discharge is to land (e.g. to a recycling pit or basin, or to an infiltration pit) effluent levels are normally not specified. The maximum daily wastewater flow of the surveyed facilities was in the 630–1600 m^3 range.

According to the cited Environment Canada study of the B.C. ready mixed concrete industry, none of the ready mixed concrete operations in the Lower Mainland systematically or routinely control the pH of wastewater effluent. Consequently, while some facilities operate within the terms of their permit, others discharge effluent which is well outside the allowable levels (pH 10.6–12.6).

A similar situation seems to occur in the case of suspended solids, with some plants meeting the requirements and others operating above the specified levels. Measured suspended solids levels range from <5–205 mg/L. Ross and Shepherd note that water with less than 2,000 mg/L of total dissolved solids is usually suitable for batch water, as is water with suspended solids concentrations of less than 2,000 mg/L.[5] The B.C. study also noted that effluent pH and TSS levels are not correlated with wastewater flow, and monitoring may occur at periods of maximum wastewater dilution.

With regard to the volume of wastewater generated by an average ready mixed concrete operation, a U.S. Environmental Protection Agency (EPA) study indicates that the mean volume for 385 plants surveyed was slightly less than 50 L/m^3 of ready mixed concrete.[6] The same study also estimated that 80% of wastewater volume is made up of washout and washoff water.

In the absence of any other additional information, we have had to make the following assumptions in order to generate effluent estimates for concrete manufacturing:

- that ready mixed concrete operations normally discharge liquid effluent at the average of the typical B.C. permit requirements (as noted in Table 14.2 for pH, TSS, and oil and grease levels);

- that essentially the same levels would be found across the country; and

- that the same contamination levels would be valid for the other concrete products with the following adjustments
  - the volume of wastewater for cement mortar is assumed to be 50% of that for ready mixed concrete because equipment washout and washoff needs are different
  - the volume of wastewater for concrete block, double T beam and hollow deck is assumed to be 25% of that for ready mixed concrete.

Table 14.3 summarizes the estimates generated by applying these assumptions.

Table 14.3
EFFLUENT CHARACTERISTICS FROM CONCRETE MANUFACTURING

	pH	TSS [mg/L]	Oil and Grease [mg/L]	Flow [L/m^3 of concrete]
Ready Mix ed Concrete	8	87.5	7.5	50
Concrete Block	8	87.5	7.5	12.5
Cement Mortar	8	87.5	7.5	25
Precast Products	8	87.5	7.5	12.5

TSS - total suspended solids

14.3 TOTAL LIQUID EFFLUENTS

Our estimate of total liquid effluents from all stages of concrete production was derived by combining the above estimates for aggregate production and concrete manufacturing with those for cement production.

To derive the totals, we first had to estimate the total effluent flows from cement, aggregate and concrete production for the seven concrete products of interest. The effluent characteristics could then be applied to the flows to estimate total liquid effluents per unit of product.

Weighted average volumes of effluent flow from the three sources in cement operations, (see Section 6.0), were obtained from the Ontario Ministry of the Environment.[7] For a cement plant, the weighted average effluent flow is about 3,295 litres per tonne of cement; for quarry water, it is about 1,827 litres per tonne of cement; and for stormwater, assuming an average of seven storm occurrences per year, it is about 3.5 litres per tonne of cement.

Based on information provided by the Ontario Ministry of the Environment, weighted average effluent flow for aggregate production in Ontario is estimated to 1,016 m^3 per day.[8] Taking into consideration that an annual total of 101,047,000 tonnes of gravel and sand aggregate is produced in Ontario[9] by 64 establishments[10] , we estimated an average quarry aggregate output volume of 1.58 Mtonnes per year, or 4,326 tonnes per day.

Using that figure and the above estimate of weighted average effluent flow yielded an estimate of 235 liters of effluent discharge per tonne of aggregate.

The above estimates for liquid effluent flows per tonne of cement and aggregate were then adjusted to take account of the volumes of these materials used in the different concrete products (from Table 10.1). The resulting estimates of effluent flow per unit of concrete product were added to the effluent flows from the concrete manufacturing step (Table 14.3) to derive the estimates of total effluent flows per unit of product shown in Table 14.4.

Table 14.4
ESTIMATED EFFLUENT FLOWS BY CONCRETE PRODUCT
(liters/m3 of concrete)

	15 MPa Ready Mix	20 MPa Ready Mix	30 MPa Ready Mix	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Cement plant water	629.43	718.40	1051.24	622.84	1011.70	1664.19	1664.19
Quarry water	349.04	398.39	582.96	345.39	561.03	922.87	922.87
Stormwater	0.68	0.77	1.13	0.67	1.09	1.79	1.79
Aggregate quarry water	468.12	454.26	426.07	399.53	184.38	350.91	350.91
Concrete process water	50.00	50.00	50.00	12.50	25.00	12.5	12.5
Totals	1497.27	1621.82	2111.41	1380.93	1783.20	2952.26	2952.26
Total liters per block or metre				13.28		876.57	501.88

Table 14.5 presents the final estimates of weighted average effluent characteristics per liter of effluent flow for each of the concrete products. These estimates were derived by combining the relevant data from section 6.0 (Table 6.0) with the data presented earlier in this section (Tables 14.1 and 14.3), with adjustments to reflect the product formulations (from Table 10.1).

Table 14.5
WEIGHTED AVERAGE LIQUID EFFLUENTS BY PRODUCT
(mg/L of effluent)

	15 MPa Ready Mix	20 MPa Ready Mix	30 MPa Ready Mix	Concrete Block	Cement Mortar	Double T Beam	Hollow Deck
Suspended Solids	54.6927	56.8203	61.9248	55.9197	68.3314	67.1835	67.1835
Aluminum	0.2427	0.2557	0.2875	0.2608	0.3276	0.3255	0.3255
Phenolics	0.0038	0.0040	0.0045	0.0041	0.0051	0.0051	0.0051
Oil & Grease	1.5590	1.5622	1.5640	1.4276	1.5622	1.4951	1.4951
Nitrate, Nitrite	0.8548	0.9007	1.0124	0.9175	1.1536	1.1462	1.1462
DOC*	1.6723	1.7621	1.9806	1.7954	2.2569	2.2424	2.2424
Chlorides	319.6894	336.8582	378.6278	343.5402	431.4521	428.6769	428.6769
Sulphates	94.7874	99.8779	112.2626	101.7230	127.9249	127.1021	127.1021
Sulphides	0.0097	0.0102	0.0115	0.0104	0.0131	0.0130	0.0130
Ammonia, -ium	0.3284	0.3460	0.3889	0.3530	0.4431	0.4403	0.4403
Phosphorus	0.0018	0.0019	0.0022	0.0020	0.0025	0.0025	0.0025
pH	8.13	8.14	8.18	8.15	8.22	8.22	8.22

* DOC - Dissolved organic compounds

Combining the estimates from Table 14.5 with the flow estimates from Table 14.4 yields the liquid effluent estimates per unit of concrete product shown in Table 14.6.

Table 14.6
WEIGHTED AVERAGE LIQUID EFFLUENTS BY PRODUCT
(grams/unit of product)

	15 MPa Ready Mix per m^3	**20 MPa Ready Mix** per m^3	**30 MPa Ready Mix** per m^3	**Concrete Block** per block	**Cement Mortar** per m^3	**Double T Beam** per m	**Hollow Deck** per m
Suspended Solids	81.8895	92.1524	130.7485	0.7425	121.8484	58.8913	33.7184
Aluminum	0.3634	0.4148	0.6069	0.0035	0.5841	0.2853	0.1633
Phenolics	0.0057	0.0065	0.0095	0.0001	0.0092	0.0045	0.0026
Oil & Grease	2.3343	2.5336	3.3022	0.0190	2.7857	1.3105	0.7504
Nitrate, Nitrite	1.2798	1.4607	2.1375	0.0122	2.0571	1.0047	0.5753
DOC*	2.5038	2.8578	4.1818	0.0238	4.0245	1.9656	1.1254
Chlorides	478.6600	546.3239	799.4373	4.5616	769.3644	375.7671	215.1464
Sulphates	141.9220	161.9842	237.0320	1.3507	228.1154	111.4144	63.7906
Sulphides	0.0145	0.0165	0.0242	0.0001	0.0233	0.0114	0.0065
Ammonia, -ium	0.4916	0.5611	0.8211	0.0047	0.7902	0.3860	0.2210
Phosphorus	0.0027	0.0031	0.0046	0.0000	0.0044	0.0022	0.0012

* DOC - Dissolved organic compounds

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[1]Harger, H. L. , *A System for 100% Recycling of Returned Concrete: Equipment, Procedures, and Affects on Product Quality* (National Ready Mixed Concrete Association Publication No.150, 1975).
[2]*Recommended Waste Management Practices for the Ready Mix Concrete Industry in British Columbia* (Environment Canada, Pacific & Yukon Region, Regional Manuscript Report MS90-03, prepared by Envirochem Services, March 1990).
[3]Verbal information, Dr. K. Donyina, Ontario Ministry of the Environment, Water Resources Branch, 8/31/93.
[4]Environment Canada, op. cit. ; and Ross, P. D. and Shepherd, R. B., *Overview of the Ready Mix Concrete Industry in British Columbia, Water and Waste Management Practices* (Environment Canada, Pacific & Yukon Region, Regional Program Report 88-03, June 1988).
[5]Ibid.
[6]*Guidance Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Concrete Products Point Source Category* (U.S. Environmental Protection Agency, 1978).
[7]Information from Ontario Ministry of the Environment, Water Resources Branch, G. Rees, 4/19/93, *MISA Monitoring Data for Ontario Cement Plants.*
[8]Donyina, op. cit.
[9]*1990 Canadian Minerals Yearbook* (Energy, Mines and Resources Canada, Ottawa, 1991), p. 41.8.
[10]*Quarries and Sand Pits, 1985* (Statistics Canada, Cat. 26-225, Nov. 1987).

15.0 SOLID WASTE

Solid wastes associated with the production of concrete products include wastes generated in the production of cement, wastes generated in the production of aggregate, and wastes produced by concrete manufacturing processes. Cement production wastes were covered in Section 7.0. This section focuses on the other two categories of wastes and then combines data for the three categories to derive total solid waste estimates for each of the concrete products.

15.1 SOLID WASTES FROM AGGREGATE PRODUCTION

Quarrying concrete aggregates is very similar to quarrying cement raw materials in terms of the generation of solid wastes (see Section 7.1). The materials are usually quarried from surface deposits and require washing, crushing and size separation. However, the rock, gravel or sand is then used in its entirety and there is no further separating, refining or smelting. As a result, there is little solid waste other than mine spoil (rock material that is not used but is moved to get to the desired resource).

15.2 SOLID WASTE FROM CONCRETE MANUFACTURING

As in the case of other unit factors, solid wastes due to the production of cement have been allocated to the manufacturing stage of concrete production. The cement component estimates shown in Table 15.1 were estimated by applying the concrete formulation factors from Table 10.1 to the estimates of cement solid wastes from Table 7.3.

Table 15.1
SOLID WASTES DUE TO THE PRODUCTION OF CEMENT: PER UNIT OF CONCRETE PRODUCT BY CITY

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
15 MPa Ready Mix [kg/m^3]	2.96	1.43	1.43	2.08	4.18	3.11
20 MPa Ready Mix [kg/m^3]	3.38	1.63	1.63	2.37	4.77	3.55
30 MPa Ready Mix [kg/m^3]	4.94	2.38	2.38	3.47	6.99	5.20
Concrete Block [kg/block]	0.0282	0.0136	0.0136	0.0198	0.0398	0.0296
Cement Mortar [kg/m^3]	4.76	2.29	2.29	3.34	6.72	5.00
Double T Beam [kg/m,10' width]	2.324	1.120	1.120	1.630	3.444	2.444
Hollow Deck [kg/m, 4'w, 8"t]	1.331	0.641	0.641	0.933	1.880	1.399

Solid wastes from concrete processing include mixer washout residue, sludges from settling basins and ponds, and off-specification products.[1] In the case of the ready mixed concrete industry, returned excess material can also end up as solid waste, unless reprocessed.

Most builders make a point of ordering excess concrete from ready mixed concrete batch operators to assure completion of daily placement activities without disruption.[2] This excess material is usually returned to the vendor for disposal. However, under the right circumstances, the returned concrete can be remixed with batches later in the day, thus reducing the amount of solid waste. The volume of returned concrete fluctuates greatly. One EPA study estimated that 1–4% of ready mixed concrete production is returned to the concrete plant.[3] Another source estimated returns to be 1.5–2%.[4] There are no comparable data available for ready mixed concrete operations in Canada.[5]

The disposal of returned concrete and waste solids generated by wastewater settling systems is an expensive and troublesome problem for ready mixed concrete operators. In the past, it was common practice to send materials to municipal landfills, but recent landfill bans have eliminated this option in many areas. As a result, appropriate disposal sites are increasingly difficult to find, and the cost of concrete disposal has approached or exceeded the value of the concrete products in some North American areas. The practice of dumping waste concrete in a vacant lot or field is no longer sensible or appropriate.

Currently, the Canadian concrete industry employs the following options for solid waste disposal:[6]

- backfilling into quarries;
- long-term storage on-site; and
- reprocessing.

Backfilling or long-term storage both result in a waste of product while reprocessing generates a value-added product which conserves the material and a portion of the embodied energy. Overseas, reprocessed concrete from demolished structures, as well as from concrete processing waste and off-specification material, is used extensively as a substitute for concrete aggregate in both civil engineering construction and in building applications.[7] In Canada, this practice is not currently widespread. The situation may change in the future, however, as new environmental regulations favour reprocessing and disposal is no longer an option.

Other available options include the use of stabilizers to allow the reuse of returned concrete[8], the production of precast concrete products,[9] paving of the yard, and the use of mechanical reclaim systems.[10]

The following assumptions were made to estimate solid wastes from ready mixed concrete manufacturing.

1. Returned concrete represents 2.125% of ready mixed concrete production. This is an average of data presented by the EPA and Harger.[11] At densities of 2,269, 2,276 and 2,287 kg/m^3 for 15 MPa, 20 MPa and 30 MPa ready mixed concrete, this represents 48.22, 48.37 and 48.60 kg, respectively, of returned concrete waste per m^3 of ready mixed concrete. We assume that 50% of this is reused in some way, yielding 24.11, 24.19 and 24.30 kg/m^3 of returned concrete as real waste.

2. Truck washouts generate 59 kg of waste per washout per m^3 mixer volume.[12] On average there are 1.5 washouts per day. Estimated ready mixed concrete truck loads

are 5.2 m^3 and each truck averages 4.2 trips per day.[13] Therefore, we have 460 kg (59 x 5.2 x 1.5) of solids from truck washout from a delivery of 21.84 m^3 (5.2 x 4.2) of ready mixed concrete per truck per day. From this we can estimate a total of 21.07 kg of waste solids per m^3 of ready mixed concrete.

3. The last major source of solid waste in a ready mixed concrete operation occurs during washout from the central mixer. Published sources give it as 73 kg per washout per m^3 of mixer capacity.[14] Assuming one washout per day of a 50 m^3 volume central mixer, and an average daily production of 330 m^3/day[15], yields an estimate of 11 kg of solid waste per m^3 of ready mixed concrete. However, in Lower Mainland, B.C., the region covered by the Ross and Shepherd study, only 4 out of 17 plants use a central mixer (others being of a dry batch type with mixing in the ready mixed concrete trucks). Therefore, taken over all operations, it can be estimated that only 2.59 kg of solid wastes per m^3 of concrete are generated from central mixer washouts.

4. Precast materials production, including concrete block, is essentially a factory operation with more process control. Furthermore, there is no returned material to be concerned about. It can be assumed that equipment washout for precast and concrete blocks is similar to that for the central mixer of a ready mix operation (i.e., 2.59 kg/m^3 of concrete). The same number is also taken for cement mortar.

Based on these assumptions, Table 15.2 summarizes our estimates for solid wastes from concrete manufacturing. In the absence of data for regions other than British Columbia, we have assumed that similar amounts of solid waste are generated in concrete producing facilities elsewhere in Canada.

Table 15.2
SOLID WASTE DUE TO CONCRETE PRODUCTS MANUFACTURING

Concrete Material	Solid Wastes
15 MPa Ready Mixed Concrete	47.77 kg/m^3
20 MPa Ready Mixed Concrete	47.85 kg/m^3
30 MPa Ready Mixed Concrete	47.96 kg/m^3
Concrete Block	0.025 kg/block
Cement Mortar	2.59 kg/m^3
Double T Beam, 10-inch width	0.769 kg/m
Hollow Deck, 4-foot width, 8-inch slab	0.440 kg/m

Combining the solid waste estimates from Tables 15.1 and 15.2 yields the final total solid waste estimates shown in Table 15.3. As noted earlier, these estimates are all assigned to the manufacturing stage of activity.

Table 15.3
ESTIMATED TOTAL SOLID WASTE DUE TO CONCRETE PRODUCTION: BY PRODUCT AND CITY

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
15 MPa Ready Mixed [kg/m^3]	50.73	49.20	49.20	49.85	51.95	50.88
20 MPa Ready Mixed [kg/m^3]	51.23	49.48	49.48	50.22	52.62	51.40
30 MPa Ready Mixed [kg/m^3]	52.90	50.34	50.34	51.43	54.95	53.16
Concrete Block [kg/block]	0.0531	0.0385	0.0385	0.0447	0.0647	0.0545
Cement Mortar [kg/m^3]	7.35	4.88	4.88	5.93	9.31	7.59
Double T Beam [kg/m]	3.093	1.889	1.889	2.399	4.053	3.213
Hollow Deck [kg/m]	1.771	1.082	1.082	1.373	2.320	1.840

[1]*Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank, Report No. 7620-R2, March 1993).
[2]*Environmental Resource Guide, Topic I-3110 4* (The American Institute of Architects, Washington, DC, October 1992).
[3]*Guidance Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Concrete Products Point Source Category* (U.S. Environmental Protection Agency, 1978).
[4]Harger, H. L., *A System for 100% Recycling of Returned Concrete: Equipment, Procedures, and Affects on Product Quality* (National Ready Mixed Concrete Association Publication No.150, 1975).
[5]*Recommended Waste Management Practices for the Ready Mix Concrete Industry in British Columbia* (Environment Canada, Pacific & Yukon Region, Regional Manuscript Report MS90-03, prepared by Envirochem Services, March 1990).
[6]Ibid.
[7]*Recycling of Demolished Concrete and Masonry* (in RILEM Report 6, edited by T.C. Hansen, E&F N Spon/Chapman & Hall, London, 1992); and *Waste Materials in Construction* (Proceedings of International Conference on Environmental Implications of Construction with Waste Materials, Maastricht, Nov. 1991, edited by J.J.M. Goumans, H.A. van der Sloot, T.G. Aalbers, Elsevier, 1991).
[8]A number of admixture chemicals suppliers have developed procedures for stopping the set of returned concrete with stabilizers/retarders to allow holding of the concrete in the truck for several hours or even overnight. Prior to the reuse of the stabilized concrete or its incorporation into the next regular batch, an activator/accelerator is added to the mix to counteract the action of the retarder. This allows leftover concrete to be reused the following day. The frequency of incorporation is difficult to determine. according to Ross and Shepherd (P.D. Ross, R. B. Shepherd, “Overview of the Ready Mix Concrete Industry in British Columbia, Water and Waste Management Practices,” Environment Canada, Pacific & Yukon Region, Regional Program Report 88-03, June 1988) one large B.C. operation estimated it to be at 60%, while another smaller operation estimated only 10%. As there is still some controversy regarding the quality, long-term performance/durability and conformance with the CSA specifications of such treated concrete, the authors of this B.C. study felt that the lower estimate may be biased to avoid questions of concrete quality.
[9]This could be an option when the returned concrete is not compatible with the next batch. While there are costs associated with this approach, they are offset by reduced handling expenses for waste solids. One B.C. operator estimates that making returned concrete into precast products has reduced his annual solids disposal costs by a factor of 2.5.
[10]These range from simple aggregate recovery to complete solids reclaim units. These systems are in widespread use in North America, but are rare in B.C. due to the initial capital outlay and perceived high maintenance costs. It is not known if this situation differs in other regions of the country.
[11]EPA, op. cit., and Harger, op. cit.
[12]Ross and Shepherd, op. cit., and EPA, op. cit.

[13]*Wastewater Treatment Studies in Aggregate and Concrete Production* (U.S. Environmental Protection Agency, PB-219 670, 1973).
[14]Ross and Shepherd, op. cit., and EPA *Guidance Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Concrete Products Point Source Category* , op. cit.
[15]Ross and Shepherd, op. cit.

16.0 SUMMARY OF CONCRETE PRODUCT UNIT FACTORS

This section summarizes the unit factors developed for concrete products in the preceding sections of Part II. As in the Part I summary this section simply shows the key tables, or table components, from the relevant sections without additional comment.

Table 16.1
RAW MATERIAL REQUIREMENTS BY CONCRETE PRODUCT: ALL REGIONS
(kg/m^3)

RAW MATERIAL	PRODUCT: 15 MPa Ready Mixed	20 MPa Ready Mixed	30 MPa Ready Mixed	Block	Double T Beam	Hollow Deck	Cement Mortar
Cement	191	218	319	189	505	505	307
SCM	19	22	31	0	0	0	0
Coarse Aggregate	970	1009	1092	510	750	750	0
Fine Aggregate	963	925	722	1191	744	744	785
Water	160	160	160	53	202	202	185
Total	2303	2334	2324	1943	2201	2201	1277

SCM - supplementary cementing materials

Table 16.2
ENERGY USE IN 15 MPA READY MIXED CONCRETE PRODUCTION: BY PROCESS STAGE AND REGION
(GJ/m^3)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.09498	0.07479	0.94716	0.23951	1.18667	1.35643
Prairie						
Calgary	0.09387	0.06461	0.94528	0.23951	1.18479	1.34326
Winnipeg	0.09387	0.05922	1.11924	0.23951	1.35875	1.51185
Central						
Toronto	0.09609	0.06747	0.89563	0.23951	1.13514	1.29870
East						
Montreal	0.09387	0.06380	1.11536	0.23951	1.35487	1.51254
Halifax	0.09387	0.05922	1.11721	0.23951	1.35672	1.50981

Note: Raw materials are coarse and fine aggregate and SCM, and extraction includes raw material processing.

Table 16.3
ENERGY USE IN 20 MPA READY MIXED CONCRETE PRODUCTION: BY PROCESS STAGE AND REGION
(GJ/m^3)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.09437	0.07717	1.08105	0.24274	1.32378	1.49533
Prairie						
Calgary	0.09309	0.06538	1.07890	0.24274	1.32164	1.48011
Winnipeg	0.09309	0.05915	1.27746	0.24274	1.52019	1.67243
Central						
Toronto	0.09566	0.06871	1.02223	0.24274	1.26497	1.42934
East						
Montreal	0.09309	0.06446	1.27303	0.24274	1.51576	1.67330
Halifax	0.09309	0.05915	1.27514	0.24274	1.51787	1.67011

Table 16.4
ENERGY USE IN 30 MPA READY MIXED CONCRETE PRODUCTION:
BY PROCESS STAGE AND REGION
(GJ/m^3)

	PROCESS STAGE					
	Raw Material	Raw Material	Manufacturing			
REGION	Extraction	Transportation	Cement	Processing	Sub-Total	TOTAL
West Coast						
Vancouver	0.08598	0.08038	1.58190	0.24170	1.82360	1.98995
Prairie						
Calgary	0.08416	0.06377	1.57876	0.24170	1.82046	1.96839
Winnipeg	0.08416	0.05499	1.86931	0.24170	2.11100	2.25016
Central						
Toronto	0.08779	0.06845	1.49584	0.24170	1.73753	1.89377
East						
Montreal	0.08416	0.06246	1.86282	0.24170	2.10452	2.25114
Halifax	0.08416	0.05499	1.86591	0.24170	2.10761	2.24676

Table 16.5
ENERGY USE IN CONCRETE BLOCK PRODUCTION:
BY PROCESS STAGE AND REGION
(GJ/block)

	PROCESS STAGE					
	Raw Material	Raw Material	Manufacturing			
REGION	Extraction	Transportation	Cement	Processing	Sub-Total	TOTAL
West Coast						
Vancouver	0.00087	0.00052	0.00901	0.01241	0.02142	0.02281
Prairie						
Calgary	0.00087	0.00052	0.00899	0.01241	0.02140	0.02279
Winnipeg	0.00087	0.00052	0.01065	0.01241	0.02306	0.02445
Central						
Toronto	0.00087	0.00052	0.00852	0.01241	0.02093	0.02232
East						
Montreal	0.00087	0.00052	0.01061	0.01241	0.02302	0.02441
Halifax	0.00087	0.00052	0.01063	0.01241	0.02304	0.02443

Table 16.6
ENERGY USE IN CEMENT MORTAR PRODUCTION:
BY PROCESS STAGE AND REGION
(GJ/m^3)

	PROCESS STAGE					
	Raw Material	Raw Material	Manufacturing			
REGION	Extraction	Transportation	Cement	Processing	Sub-Total	TOTAL
West Coast						
Vancouver	0.04663	0.02779	1.52239	0.00395	1.52634	1.60076
Prairie						
Calgary	0.04663	0.02779	1.51937	0.00395	1.52332	1.59774
Winnipeg	0.04663	0.02779	1.79899	0.00395	1.80294	1.87736
Central						
Toronto	0.04663	0.02779	1.43957	0.00395	1.44352	1.51794
East						
Montreal	0.04663	0.02779	1.79275	0.00395	1.79670	1.87112
Halifax	0.04663	0.02779	1.79572	0.00395	1.79967	1.87409

Table 16.7
ENERGY USE IN DOUBLE T BEAM PRODUCTION:
BY PROCESS STAGE AND REGION
(GJ/metre of 10' wide beam)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.02154	0.01792	0.74356	0.14483	0.88839	0.92785
Prairie						
Calgary	0.02154	0.01792	0.74208	0.14483	0.88691	0.92637
Winnipeg	0.02154	0.01792	0.87865	0.14483	1.02348	1.06294
Central						
Toronto	0.02154	0.01792	0.70310	0.14483	0.84793	0.88739
East						
Montreal	0.02154	0.01792	0.87560	0.14483	1.02043	1.05989
Halifax	0.02154	0.01792	0.87705	0.14483	1.02188	1.06134

Note: Raw material extraction covers coarse and fine aggregate and includes processing; raw material transportation also includes transportation of reinforcing steel.

Table 16.8
ENERGY USE IN HOLLOW DECK PRODUCTION:
BY PROCESS STAGE AND REGION
(GJ/metre of 4' wide by 8" deep slab)

REGION	PROCESS STAGE: Raw Material Extraction	Raw Material Transportation	Manufacturing: Cement	Manufacturing: Processing	Manufacturing: Sub-Total	TOTAL
West Coast						
Vancouver	0.01233	0.01033	0.42572	0.08292	0.50864	0.53130
Prairie						
Calgary	0.01233	0.01033	0.42488	0.08292	0.50780	0.53046
Winnipeg	0.01233	0.01033	0.50307	0.08292	0.58599	0.60865
Central						
Toronto	0.01233	0.01033	0.40256	0.08292	0.48548	0.50814
East						
Montreal	0.01233	0.01033	0.50133	0.08292	0.58425	0.60691
Halifax	0.01233	0.01033	0.50216	0.08292	0.58508	0.60774

Table 16.9
ESTIMATED WATER USE IN THE
READY MIXED CONCRETE INDUSTRY: ALL REGIONS

Category	Litre/m^3
Batch Water	139 - 188
Truck Washout	15 - 317
Truck Washoff	5 - 69
Miscellaneous	15 - 129
Total	**174 - 703**

Table 16.10
TOTAL ATMOSPHERIC EMISSIONS DUE TO CONCRETE PRODUCTION: BY PRODUCT AND REGION

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
15 MPa Ready Mixed Concrete (grams/m³)								
West Coast	Vancouver	176707.33	52.10	1111.50	34.33	8.02	167.01	469.93
Prairies	Calgary	162128.70	44.20	1372.27	33.73	8.81	167.79	556.53
	Winnipeg	174041.78	61.39	1653.66	44.23	9.06	147.79	556.53
Central	Toronto	180563.27	59.80	568.25	30.64	7.47	186.89	442.28
East	Montreal	194805.34	76.84	810.79	31.35	7.78	191.43	540.86
	Halifax	194619.71	77.01	804.49	31.56	7.82	191.88	491.34
20 MPa Ready Mixed Concrete (grams/m³)								
West Coast	Vancouver	196797.12	51.26	1213.27	33.07	7.97	171.43	505.79
Prairies	Calgary	180992.86	44.88	1526.58	34.28	9.00	169.91	604.63
	Winnipeg	195024.19	65.12	1852.70	46.80	9.42	149.80	604.63
Central	Toronto	201801.80	62.35	606.26	30.47	7.39	190.26	474.23
East	Montreal	218331.95	79.96	890.41	29.87	7.72	200.13	586.74
	Halifax	218511.05	82.95	883.49	32.34	8.00	200.13	530.22
30 MPa Ready Mixed Concrete (grams/m³)								
West Coast	Vancouver	276954.14	60.14	1674.06	37.69	8.97	195.93	633.72
Prairies	Calgary	253827.72	50.80	2132.53	39.47	10.48	193.70	778.36
	Winnipeg	274359.80	80.43	2609.74	57.78	11.09	164.27	778.36
Central	Toronto	284277.49	76.37	785.82	33.89	8.13	223.48	587.54
East	Montreal	308466.11	102.15	1201.62	33.01	8.61	237.91	752.18
	Halifax	308728.19	106.51	1191.50	36.62	9.02	237.92	669.48
Concrete Block (grams/block)								
West Coast	Vancouver	2126.02	0.51	11.60	0.39	0.10	2.10	4.38
Prairies	Calgary	1994.27	0.46	14.21	0.40	0.11	2.09	5.20
	Winnipeg	2111.24	0.63	16.93	0.51	0.12	1.92	5.20
Central	Toronto	2167.74	0.61	6.54	0.37	0.10	2.26	4.12
East	Montreal	2305.54	0.75	8.91	0.37	0.10	2.34	5.05
	Halifax	2307.03	0.78	8.85	0.39	0.10	2.34	4.58
Cement Mortar (grams/m³)								
West Coast	Vancouver	248598.86	34.12	1456.47	20.07	4.55	105.09	566.36
Prairies	Calgary	226342.41	25.14	1897.69	21.77	6.00	102.94	705.56
	Winnipeg	246102.12	53.64	2356.96	39.40	6.59	74.62	705.56
Central	Toronto	255646.73	49.74	601.65	16.40	3.74	131.60	521.91
East	Montreal	278925.43	74.55	1001.81	15.56	4.20	145.50	680.36
	Halifax	279177.65	78.75	992.06	19.03	4.59	145.50	600.77
Double T Beams (grams/metre of 10´ wide beam)								
West Coast	Vancouver	128211.56	19.43	738.87	12.26	2.93	64.71	256.67
Prairies	Calgary	117341.24	15.04	954.36	13.09	3.64	63.67	324.65
	Winnipeg	126992.12	28.96	1178.67	21.70	3.93	49.84	324.65
Central	Toronto	131653.83	27.06	321.36	10.47	2.54	77.66	234.96
East	Montreal	143023.43	39.17	516.80	10.05	2.76	84.45	312.35
	Halifax	143146.62	41.23	512.04	11.75	2.96	84.45	273.47
Hollow Deck (grams/metre of 4´ wide by 8¨ deep slab)								
West Coast	Vancouver	73412.78	11.13	423.10	7.02	1.68	37.08	146.94
Prairie	Calgary	67188.95	8.62	546.48	7.50	2.09	36.48	185.87
	Winnipeg	72714.58	16.59	674.91	12.43	2.25	28.56	185.87
Central	Toronto	75383.66	15.50	184.05	6.00	1.45	44.50	134.52
East	Montreal	81893.35	22.44	295.95	5.76	1.58	48.38	178.82
	Halifax	81963.88	23.61	293.23	6.73	1.69	48.38	156.57

Table 16.11
WEIGHTED AVERAGE LIQUID EFFLUENTS BY PRODUCT: ALL REGIONS
(grams/unit of product)

	15 MPa Ready Mix per m^3	**20 MPa Ready Mix** per m^3	**30 MPa Ready Mix** per m^3	**Concrete Block** per block	**Cement Mortar** per m^3	**Double T Beam** per m	**Hollow Deck** per m
Suspended Solids	81.8895	92.1524	130.7485	0.7425	121.8484	58.8913	33.7184
Aluminum	0.3634	0.4148	0.6069	0.0035	0.5841	0.2853	0.1633
Phenolics	0.0057	0.0065	0.0095	0.0001	0.0092	0.0045	0.0026
Oil & Grease	2.3343	2.5336	3.3022	0.0190	2.7857	1.3105	0.7504
Nitrate, Nitrite	1.2798	1.4607	2.1375	0.0122	2.0571	1.0047	0.5753
DOC	2.5038	2.8578	4.1818	0.0238	4.0245	1.9656	1.1254
Chlorides	478.6600	546.3239	799.4373	4.5616	769.3644	375.7671	215.1464
Sulphates	141.9220	161.9842	237.0320	1.3507	228.1154	111.4144	63.7906
Sulphides	0.0145	0.0165	0.0242	0.0001	0.0233	0.0114	0.0065
Ammonia, -ium	0.4916	0.5611	0.8211	0.0047	0.7902	0.3860	0.2210
Phosphorus	0.0027	0.0031	0.0046	0.0000	0.0044	0.0022	0.0012

Table 16.12
ESTIMATED TOTAL SOLID WASTES DUE TO CONCRETE PRODUCTION: BY PRODUCT AND CITY

Product	Vancouver	Calgary	Winnipeg	Toronto	Montreal	Halifax
15 MPa Ready Mixed [kg/m^3]	50.73	49.20	49.20	49.85	51.95	50.88
20 MPa Ready Mixed [kg/m^3]	51.23	49.48	49.48	50.22	52.62	51.40
30 MPa Ready Mixed [kg/m^3]	52.90	50.34	50.34	51.43	54.95	53.16
Concrete Block [kg/block]	0.0531	0.0385	0.0385	0.0447	0.0647	0.0545
Cement Mortar [kg/m^3]	7.35	4.88	4.88	5.93	9.31	7.59
Double T Beam [kg/m]	3.093	1.889	1.889	2.399	4.053	3.213
Hollow Deck [kg/m]	1.771	1.082	1.082	1.373	2.320	1.840

APPENDICES

APPENDIX A
CEMENT AND CONCRETE PRODUCT ATMOSPHERIC EMISSIONS INCLUDING ELECTRICITY-RELATED EMISSIONS

Table A.1
ATMOSPHERIC EMISSIONS DUE TO CEMENT RAW MATERIALS TRANSPORTATION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO
West Coast	Vancouver	6668.94	38.97	23.47	30.21	3.45	3.90
Prairies	Calgary	15946.90	24.94	293.61	16.34	2.26	26.77
	Winnipeg	15946.90	24.94	293.61	16.34	2.26	26.77
Central	Toronto	4958.77	23.07	39.06	14.31	1.94	13.42
East	Montreal	1714.06	8.08	14.19	4.13	0.63	6.51
	Halifax	1714.06	8.08	14.19	4.13	0.63	6.51

Table A.2
ATMOSPHERIC EMISSIONS DUE TO CEMENT MANUFACTURING
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	827275.20	1530.88	4871.64	7.97	4.58	188.15	483.06
Prairies	Calgary	734435.39	1670.77	5897.38	6.96	5.41	52.71	938
	Winnipeg	734435.39	1670.77	5897.38	6.96	5.41	52.71	938
Central	Toronto	856189.09	1716.75	2120.21	8.01	3.28	273.95	340.32
East	Montreal	924541.76	1720.87	3305.19	10.45	4.31	280.31	863.23
	Halifax	924541.76	1720.87	3305.19	10.45	4.31	280.31	603

Table A.3
FUEL AND CALCINATION CO_2 CEMENT MANUFACTURING EMISSIONS
(g/tonne of cement)

Region	City	Calcination CO_2	Fuel Manufact. CO_2	Total Manufact. CO_2	Calcination CO_2 as % of Total Manufact. CO_2	Grand Ttl CO_2
West Coast	Vancouver	498334.83	328940.37	827275.20	60.24	846643.12
Prairie	Calgary	498334.83	236100.56	734435.39	67.85	779932.77
	Winnipeg	498334.83	236100.56	734435.39	67.85	844296.64
Central	Toronto	498334.83	357854.26	856189.09	58.20	873610.52
East	Montreal	498334.83	426206.93	924541.76	53.90	946669.83
	Halifax	498334.83	426206.93	924541.76	53.90	947491.40

Table A.4
SO_2 CEMENT MANUFACTURING EMISSIONS CORRECTED AS PER GAGAN
(g/tonne of cement)

Region	City	Pyroproces. fuel SO_2	Correct. fuel pyropr.SO_2	Cor.ttl mnfct. SO_2	Cor.grndttl. SO_2
West Coast	Vancouver	1433.55	472.12	1530.88	1588.18
Prairies	Calgary	508.12	507.45	1670.77	1738.34
	Winnipeg	508.12	507.45	1670.77	1831.20
Central	Toronto	3164.08	578.68	1716.75	1763.42
East	Montreal	5341.31	584.67	1720.87	1758.41
	Halifax	5341.31	584.67	1720.87	1772.10

Table A.5
NO_X CEMENT MANUFACTURING EMISSIONS
(g/tonne of cement)

Region	City	Pyroproc. NO_x	Fuel NO_x	T + P NO_x	Ttl mnfct. NO_x	Grndttl. NO_x
West Coast	Vancouver	4439.56	565.85	3873.70	4871.64	5040.06
Prairies	Calgary	5413.33	207.34	5205.99	5897.38	6528.29
	Winnipeg	5413.33	207.34	5205.99	5897.38	8024.26
Central	Toronto	1652.17	788.20	863.97	2120.21	2290.98
East	Montreal	2860.09	927.94	1932.15	3305.19	3570.03
	Halifax	2860.09	927.94	1932.15	3305.19	3538.29

Table A.6
TOTAL ATMOSPHERIC EMISSIONS DUE TO CEMENT PRODUCTION
(g/tonne of cement)

Region	City	CO_2	SO_2	NO_x	VOC	CH_4	CO	TPM
West Coast	Vancouver	846643.12	1588.18	5040.06	53.78	11.93	271.62	1326.09
Prairies	Calgary	779932.77	1738.34	6528.29	59.62	16.73	264.64	1779.50
	Winnipeg	844296.64	1831.20	8024.26	117.03	18.64	172.39	1779.50
Central	Toronto	873610.52	1763.42	2290.98	42.04	9.33	357.99	1181.31
East	Montreal	946669.83	1758.41	3570.03	39.17	10.79	403.24	1697.43
	Halifax	947491.40	1772.10	3538.29	50.48	12.09	403.25	1438.17

Table A.7
ATMOSPHERIC EMISSIONS DUE TO FINE & COARSE AGGREGATES PRODUCTION

	CO_2 [kg/t]	SO_2 [g/t]	NO_x [g/t]	VOC [g/t]	CH_4 [g/t]	CO [g/t]	TPM [g/t]
Extraction							
Coarse Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Fine Aggregate	1.9089	2.7540	21.7890	2.3463	0.5859	11.9610	
Process							
Coarse Aggregate	0.9100	28.2204	8.0244	0.0432	0.0108	0.0000	
Fine Aggregate	2.7301	84.6612	24.0732	0.1296	0.0324	0.0000	
Transportation							
Coarse Aggregate	1.6685	2.4072	19.0452	2.0508	0.5121	10.4548	
Fine Aggregate	2.5028	3.6108	28.5678	3.0763	0.7682	15.6822	
Total							
Coarse Aggregate	4.4875	33.3816	48.8586	4.4403	1.1088	22.4158	50.0000
Fine Aggregate	7.1418	91.0260	74.4300	5.5522	1.3865	27.6432	50.0000

Table A.8
ATMOSPHERIC EMISSIONS DUE TO SCM TRANSPORTATION AND PROCESSING

City	CO_2 [kg/t]	SO_2 [g/t]	NOx [g/t]	VOC [g/t]	CH_4 [g/t]	CO [g/t]
Vancouver	71.8080	162.5428	1046.4565	122.2673	14.3112	66.6598
Calgary	28.3648	40.9224	323.7684	34.8643	8.7060	177.7316
Winnipeg	8.3426	12.0360	95.2260	10.2542	2.5606	52.2740
Toronto	48.8996	56.6341	445.7446	47.9901	11.9837	244.6423
Montreal	26.3713	141.0180	107.6130	113.1271	13.2803	28.3570
Halifax	8.3426	12.0360	95.2260	10.2542	2.5606	52.2740

Table A.9
ATMOSPHERIC EMISSIONS DUE TO 15 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	7295.38	117.13	73.91	4.71	1.18	23.12	96.65
Prairie	Calgary	7201.75	114.23	73.08	4.70	1.17	23.12	96.65
	Winnipeg	7201.75	114.23	73.08	4.70	1.17	23.12	96.65
Central	Toronto	7389.02	120.03	74.74	4.71	1.18	23.12	96.65
East	Montreal	7201.75	114.23	73.08	4.70	1.17	23.12	96.65
	Halifax	7201.75	114.23	73.08	4.70	1.17	23.12	96.65
Aggregate Transportation								
West Coast	Vancouver	5299.35	8.90	65.87	7.27	1.51	26.51	
Prairie	Calgary	4567.57	6.59	52.14	5.61	1.40	28.62	
	Winnipeg	4187.15	6.04	47.79	5.15	1.29	26.24	
Central	Toronto	4770.47	6.88	54.45	5.86	1.46	29.89	
East	Montreal	4529.70	8.49	48.03	7.10	1.49	25.78	
	Halifax	4187.15	6.04	47.79	5.15	1.29	26.24	
Concrete Processing								
West Coast	Vancouver	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
Prairie	Calgary	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
	Winnipeg	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
Central	Toronto	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
East	Montreal	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
	Halifax	16371.29	55.86	132.23	12.74	3.22	65.50	120.00
Cement Production								
West Coast	Vancouver	161708.84	303.34	962.65	10.27	2.28	51.88	253.28
Prairie	Calgary	148967.16	332.02	1246.90	11.39	3.20	50.55	339.88
	Winnipeg	161260.66	349.76	1532.63	22.35	3.56	32.93	339.88
Central	Toronto	166859.61	336.81	437.58	8.03	1.78	68.38	225.63
East	Montreal	180813.94	335.86	681.88	7.48	2.06	77.02	324.21
	Halifax	180970.86	338.47	675.81	9.64	2.31	77.02	274.69
Processing Sub-total								
West Coast	Vancouver	178080.12	359.20	1094.88	23.01	5.50	117.38	373.28
Prairie	Calgary	165338.44	387.89	1379.13	24.12	6.42	116.05	459.88
	Winnipeg	177631.94	405.62	1664.86	35.09	6.78	98.43	459.88
Central	Toronto	183230.89	392.68	569.81	20.76	5.00	133.88	345.63
East	Montreal	197185.22	391.72	814.11	20.22	5.28	142.52	444.21
	Halifax	197342.14	394.33	808.04	22.38	5.53	142.52	394.69
TOTAL								
West Coast	Vancouver	190674.86	485.23	1234.66	34.99	8.18	167.01	469.93
Prairie	Calgary	177107.77	508.70	1504.35	34.44	8.99	167.79	556.53
	Winnipeg	189020.84	525.89	1785.74	44.94	9.24	147.79	556.53
Central	Toronto	195390.38	519.59	698.99	31.34	7.64	186.89	442.28
East	Montreal	208916.67	514.44	935.22	32.02	7.95	191.43	540.86
	Halifax	208731.04	514.60	928.92	32.23	7.99	191.88	491.34

Table A.10
ATMOSPHERIC EMISSIONS DUE TO 20 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	7243.82	115.47	73.46	4.71	1.18	23.13	96.70
Prairie	Calgary	7135.41	112.11	72.50	4.70	1.17	23.13	96.70
	Winnipeg	7135.41	112.11	72.50	4.70	1.17	23.13	96.70
Central	Toronto	7352.24	118.84	74.42	4.71	1.18	23.13	96.70
East	Montreal	7135.41	112.11	72.50	4.70	1.17	23.13	96.70
	Halifax	7135.41	112.11	72.50	4.70	1.17	23.13	96.70
Aggregate Transportation								
West Coast	Vancouver	5094.72	8.80	64.38	7.14	1.43	24.17	
Prairie	Calgary	4247.40	6.13	48.48	5.22	1.30	26.61	
	Winnipeg	3806.91	5.49	43.45	4.68	1.17	23.85	
Central	Toronto	4482.33	6.47	51.16	5.51	1.38	28.09	
East	Montreal	4203.54	8.33	43.73	6.94	1.40	23.33	
	Halifax	3806.91	5.49	43.45	4.68	1.17	23.85	
Concrete Processing								
West Coast	Vancouver	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
Prairie	Calgary	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
	Winnipeg	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
Central	Toronto	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
East	Montreal	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
	Halifax	16591.65	56.61	134.01	12.91	3.26	66.39	120.00
Cement Production								
West Coast	Vancouver	184568.20	346.22	1098.73	11.72	2.60	59.21	289.09
Prairie	Calgary	170025.34	378.96	1423.17	13.00	3.65	57.69	387.93
	Winnipeg	184056.67	399.20	1749.29	25.51	4.06	37.58	387.93
Central	Toronto	190447.09	384.42	499.43	9.16	2.03	78.04	257.53
East	Montreal	206374.02	383.33	778.27	8.54	2.35	87.91	370.04
	Halifax	206553.12	386.32	771.35	11.00	2.64	87.91	313.52
Processing Sub-total								
West Coast	Vancouver	201159.86	402.84	1232.74	24.63	5.86	125.60	409.09
Prairie	Calgary	186617.00	435.57	1557.18	25.90	6.91	124.08	507.93
	Winnipeg	200648.32	455.82	1883.30	38.42	7.33	103.97	507.93
Central	Toronto	207038.75	441.04	633.44	22.07	5.30	144.43	377.53
East	Montreal	222965.68	439.95	912.28	21.45	5.62	154.29	490.04
	Halifax	223144.78	442.93	905.36	23.91	5.90	154.29	433.52
TOTAL								
West Coast	Vancouver	212027.05	523.54	1347.56	33.79	8.15	171.44	505.79
Prairie	Calgary	197375.78	552.91	1671.04	35.06	9.20	169.91	604.63
	Winnipeg	211407.10	573.16	1997.16	47.58	9.61	149.80	604.63
Central	Toronto	218014.37	565.10	749.22	31.24	7.59	190.26	474.23
East	Montreal	233724.46	557.29	1026.14	30.60	7.90	200.13	586.74
	Halifax	233903.56	560.27	1019.22	33.07	8.19	200.13	530.22

Table A.11
ATMOSPHERIC EMISSIONS DUE TO 30 MPA READY MIXED CONCRETE PRODUCTION BY PROCESS STAGE AND REGION
(grams/m³)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	6580.43	101.68	67.02	4.40	1.10	21.70	90.70
Prairie	Calgary	6427.66	96.94	65.67	4.40	1.10	21.70	90.70
	Winnipeg	6427.66	96.94	65.67	4.40	1.10	21.70	90.70
Central	Toronto	6733.20	106.41	68.36	4.41	1.10	21.70	90.70
East	Montreal	6427.66	96.94	65.67	4.40	1.10	21.70	90.70
	Halifax	6427.66	96.94	65.67	4.40	1.10	21.70	90.70
Aggregate Transportation								
West Coast	Vancouver	5501.51	9.98	71.57	8.00	1.50	23.55	
Prairie	Calgary	4307.55	6.21	49.17	5.29	1.32	26.99	
	Winnipeg	3686.86	5.32	42.08	4.53	1.13	23.10	
Central	Toronto	4638.59	6.69	52.95	5.70	1.42	29.06	
East	Montreal	4245.75	9.32	42.47	7.72	1.46	22.36	
	Halifax	3686.86	5.32	42.08	4.53	1.13	23.10	
Concrete Processing								
West Coast	Vancouver	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
Prairie	Calgary	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
	Winnipeg	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
Central	Toronto	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
East	Montreal	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
	Halifax	16520.57	56.37	133.44	12.85	3.25	66.10	120.00
Cement Production								
West Coast	Vancouver	270079.16	506.63	1607.78	17.16	3.80	86.65	423.02
Prairie	Calgary	248798.55	554.53	2082.52	19.02	5.34	84.42	567.66
	Winnipeg	269330.63	584.15	2559.74	37.33	5.95	54.99	567.66
Central	Toronto	278681.76	562.53	730.82	13.41	2.98	114.20	376.84
East	Montreal	301987.68	560.93	1138.84	12.49	3.44	128.63	541.48
	Halifax	302249.76	565.30	1128.71	16.10	3.86	128.64	458.77
Processing Sub-total								
West Coast	Vancouver	286599.72	563.00	1741.22	30.01	7.05	152.75	543.02
Prairie	Calgary	265319.12	610.90	2215.96	31.87	8.59	150.52	687.66
	Winnipeg	285851.19	640.52	2693.17	50.19	9.20	121.09	687.66
Central	Toronto	295202.32	618.90	864.26	26.26	6.23	180.30	496.84
East	Montreal	318508.24	617.30	1272.28	25.35	6.69	194.74	661.48
	Halifax	318770.32	621.67	1262.15	28.96	7.11	194.74	578.77
TOTAL								
West Coast	Vancouver	296608.40	669.62	1847.36	38.63	9.21	195.93	633.72
Prairie	Calgary	275175.02	712.79	2320.76	40.48	10.74	193.70	778.36
	Winnipeg	295707.09	742.41	2797.98	58.80	11.35	164.27	778.36
Central	Toronto	305363.77	730.26	971.75	34.89	8.38	223.48	587.54
East	Montreal	328364.14	719.19	1377.08	33.96	8.84	237.91	752.18
	Halifax	328626.22	723.55	1366.95	37.57	9.26	237.92	669.47

Table A.12
ATMOSPHERIC EMISSIONS DUE TO CONCRETE BLOCK PRODUCTION BY PROCESS STAGE AND REGION
(grams/block)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	66.95	1.15	0.67	0.04	0.01	0.20	0.82
Prairie	Calgary	66.95	1.15	0.67	0.04	0.01	0.20	0.82
	Winnipeg	66.95	1.15	0.67	0.04	0.01	0.20	0.82
Central	Toronto	66.95	1.15	0.67	0.04	0.01	0.20	0.82
East	Montreal	66.95	1.15	0.67	0.04	0.01	0.20	0.82
	Halifax	66.95	1.15	0.67	0.04	0.01	0.20	0.82
Aggregate Transportation								
West Coast	Vancouver	36.76	0.05	0.42	0.05	0.01	0.23	
Prairie	Calgary	36.76	0.05	0.42	0.05	0.01	0.23	
	Winnipeg	36.76	0.05	0.42	0.05	0.01	0.23	
Central	Toronto	36.76	0.05	0.42	0.05	0.01	0.23	
East	Montreal	36.76	0.05	0.42	0.05	0.01	0.23	
	Halifax	36.76	0.05	0.42	0.05	0.01	0.23	
Concrete Processing								
West Coast	Vancouver	707.70	3.37	3.32	0.22	0.06	1.18	1.15
Prairie	Calgary	707.70	3.37	3.32	0.22	0.06	1.18	1.15
	Winnipeg	707.70	3.37	3.32	0.22	0.06	1.18	1.15
Central	Toronto	707.70	3.37	3.32	0.22	0.06	1.18	1.15
East	Montreal	707.70	3.37	3.32	0.22	0.06	1.18	1.15
	Halifax	707.70	3.37	3.32	0.22	0.06	1.18	1.15
Cement Production								
West Coast	Vancouver	1538.60	2.89	9.16	0.10	0.02	0.49	2.41
Prairie	Calgary	1417.37	3.16	11.86	0.11	0.03	0.48	3.23
	Winnipeg	1534.34	3.33	14.58	0.21	0.03	0.31	3.23
Central	Toronto	1587.61	3.20	4.16	0.08	0.02	0.65	2.15
East	Montreal	1720.38	3.20	6.49	0.07	0.02	0.73	3.08
	Halifax	1721.88	3.22	6.43	0.09	0.02	0.73	2.61
Processing Sub-total								
West Coast	Vancouver	2246.30	6.25	12.48	0.32	0.09	1.68	3.56
Prairie	Calgary	2125.07	6.53	15.19	0.33	0.09	1.66	4.38
	Winnipeg	2242.04	6.70	17.91	0.43	0.10	1.50	4.38
Central	Toronto	2295.31	6.57	7.49	0.30	0.08	1.83	3.30
East	Montreal	2428.08	6.56	9.81	0.29	0.08	1.92	4.23
	Halifax	2429.57	6.59	9.75	0.31	0.09	1.92	3.76
TOTAL								
West Coast	Vancouver	2350.01	7.46	13.57	0.40	0.11	2.10	4.38
Prairie	Calgary	2228.78	7.73	16.28	0.42	0.12	2.09	5.20
	Winnipeg	2345.75	7.90	19.00	0.52	0.12	1.92	5.20
Central	Toronto	2399.02	7.78	8.58	0.38	0.10	2.26	4.12
East	Montreal	2531.79	7.77	10.90	0.38	0.11	2.34	5.05
	Halifax	2533.29	7.79	10.85	0.40	0.11	2.34	4.58

Table A.13
ATMOSPHERIC EMISSIONS DUE TO CEMENT MORTAR PRODUCTION BY PROCESS STAGE AND REGION
(grams/m^3)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
Prairie	Calgary	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
	Winnipeg	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
Central	Toronto	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
East	Montreal	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
	Halifax	3641.63	68.62	36.00	1.94	0.49	9.39	39.25
Aggregate Transportation								
West Coast	Vancouver	1964.68	2.83	22.43	2.41	0.60	12.31	
Prairie	Calgary	1964.68	2.83	22.43	2.41	0.60	12.31	
	Winnipeg	1964.68	2.83	22.43	2.41	0.60	12.31	
Central	Toronto	1964.68	2.83	22.43	2.41	0.60	12.31	
East	Montreal	1964.68	2.83	22.43	2.41	0.60	12.31	
	Halifax	1964.68	2.83	22.43	2.41	0.60	12.31	
Concrete Processing								
West Coast	Vancouver	332.84	10.32	2.93	0.02	0.00	0.00	120.00
Prairie	Calgary	332.84	10.32	2.93	0.02	0.00	0.00	120.00
	Winnipeg	332.84	10.32	2.93	0.02	0.00	0.00	120.00
Central	Toronto	332.84	10.32	2.93	0.02	0.00	0.00	120.00
East	Montreal	332.84	10.32	2.93	0.02	0.00	0.00	120.00
	Halifax	332.84	10.32	2.93	0.02	0.00	0.00	120.00
Cement Production								
West Coast	Vancouver	259919.44	487.57	1547.30	16.51	3.66	83.39	407.11
Prairie	Calgary	239439.36	533.67	2004.19	18.30	5.14	81.24	546.31
	Winnipeg	259199.07	562.18	2463.45	35.93	5.72	52.92	546.31
Central	Toronto	268198.43	541.37	703.33	12.90	2.86	109.90	362.66
East	Montreal	290627.64	539.83	1096.00	12.02	3.31	123.80	521.11
	Halifax	290879.86	544.03	1086.25	15.50	3.71	123.80	441.52
Processing Sub-total								
West Coast	Vancouver	260252.28	497.89	1550.23	16.53	3.66	83.39	527.11
Prairie	Calgary	239772.20	543.99	2007.12	18.32	5.14	81.24	666.31
	Winnipeg	259531.91	572.50	2466.38	35.95	5.73	52.92	666.31
Central	Toronto	268531.27	551.69	706.27	12.92	2.87	109.90	482.66
East	Montreal	290960.48	550.15	1098.93	12.04	3.32	123.80	641.11
	Halifax	291212.70	554.35	1089.19	15.51	3.72	123.80	561.52
TOTAL								
West Coast	Vancouver	265858.59	569.35	1608.66	20.89	4.75	105.09	566.36
Prairie	Calgary	245378.51	615.45	2065.55	22.68	6.23	102.94	705.56
	Winnipeg	265138.22	643.95	2524.81	40.30	6.82	74.62	705.56
Central	Toronto	274137.58	623.15	764.69	17.28	3.96	131.60	521.91
East	Montreal	296566.79	621.61	1157.36	16.40	4.41	145.50	680.36
	Halifax	296819.01	625.81	1147.62	19.87	4.80	145.50	600.77

Table A.14
ATMOSPHERIC EMISSIONS DUE TO DOUBLE T BEAM PRODUCTION
BY PROCESS STAGE AND REGION
(grams/metre of 10´ wide beam)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
Prairie	Calgary	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
	Winnipeg	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
Central	Toronto	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
East	Montreal	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
	Halifax	1652.54	26.21	16.77	1.08	0.27	5.31	22.19
Aggregate Transportation								
West Coast	Vancouver	1267.28	1.83	14.47	1.56	0.39	7.94	
Prairie	Calgary	1267.28	1.83	14.47	1.56	0.39	7.94	
	Winnipeg	1267.28	1.83	14.47	1.56	0.39	7.94	
Central	Toronto	1267.28	1.83	14.47	1.56	0.39	7.94	
East	Montreal	1267.28	1.83	14.47	1.56	0.39	7.94	
	Halifax	1267.28	1.83	14.47	1.56	0.39	7.94	
Concrete Processing								
West Coast	Vancouver	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
Prairie	Calgary	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
	Winnipeg	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
Central	Toronto	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
East	Montreal	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
	Halifax	8517.82	68.75	41.62	2.04	0.61	10.74	35.64
Cement Production								
West Coast	Vancouver	126947.85	238.14	755.72	8.06	1.79	40.73	198.84
Prairie	Calgary	116945.13	260.65	978.87	8.94	2.51	39.68	266.82
	Winnipeg	126596.02	274.57	1203.18	17.55	2.80	25.85	266.82
Central	Toronto	130991.42	264.41	343.52	6.30	1.40	53.68	177.13
East	Montreal	141946.12	263.66	535.30	5.87	1.62	60.46	254.52
	Halifax	142069.30	265.71	530.54	7.57	1.81	60.46	215.64
Processing Sub-total								
West Coast	Vancouver	135465.68	306.89	797.34	10.10	2.40	51.47	234.48
Prairie	Calgary	125462.95	329.40	1020.49	10.98	3.12	50.42	302.46
	Winnipeg	135113.84	343.32	1244.80	19.59	3.40	36.59	302.46
Central	Toronto	139509.24	333.16	385.14	8.34	2.01	64.42	212.77
East	Montreal	150463.94	332.41	576.92	7.91	2.23	71.20	290.16
	Halifax	150587.13	334.46	572.16	9.61	2.42	71.20	251.28
TOTAL								
West Coast	Vancouver	138385.50	334.92	828.58	12.74	3.05	64.71	256.67
Prairie	Calgary	128382.77	357.44	1051.72	13.61	3.77	63.67	324.65
	Winnipeg	138033.66	371.36	1276.03	22.22	4.06	49.84	324.65
Central	Toronto	142429.06	361.20	416.37	10.98	2.66	77.66	234.96
East	Montreal	153383.76	360.45	608.16	10.55	2.88	84.45	312.35
	Halifax	153506.95	362.50	603.40	12.24	3.08	84.45	273.47

Table A.15
ATMOSPHERIC EMISSIONS DUE TO HOLLOW DECK PRODUCTION BY PROCESS STAGE AND REGION
(grams/metre of 4´ wide by 8¨ deep slab)

		CO_2	SO_2	NO_X	VOC	CH_4	CO	TPM
Aggregate Extraction and Processing								
West Coast	Vancouver	946.16	15.01	9.60	0.62	0.15	3.04	12.70
Prairie	Calgary	946.16	15.01	9.60	0.62	0.15	3.04	12.70
	Winnipeg	946.16	15.01	9.60	0.62	0.15	3.04	12.70
Central	Toronto	946.16	15.01	9.60	0.62	0.15	3.04	12.70
East	Montreal	946.16	15.01	9.60	0.62	0.15	3.04	12.70
	Halifax	946.16	15.01	9.60	0.62	0.15	3.04	12.70
Aggregate Transportation								
West Coast	Vancouver	730.51	1.05	8.34	0.90	0.22	4.58	
Prairie	Calgary	730.51	1.05	8.34	0.90	0.22	4.58	
	Winnipeg	730.51	1.05	8.34	0.90	0.22	4.58	
Central	Toronto	730.51	1.05	8.34	0.90	0.22	4.58	
East	Montreal	730.51	1.05	8.34	0.90	0.22	4.58	
	Halifax	730.51	1.05	8.34	0.90	0.22	4.58	
Concrete Processing								
West Coast	Vancouver	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
Prairie	Calgary	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
	Winnipeg	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
Central	Toronto	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
East	Montreal	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
	Halifax	4876.90	39.36	23.83	1.17	0.35	6.15	20.40
Cement Production								
West Coast	Vancouver	72684.31	136.34	432.69	4.62	1.02	23.32	113.84
Prairie	Calgary	66957.23	149.24	560.45	5.12	1.44	22.72	152.77
	Winnipeg	72482.87	157.21	688.88	10.05	1.60	14.80	152.77
Central	Toronto	74999.46	151.39	196.68	3.61	0.80	30.73	101.42
East	Montreal	81271.61	150.96	306.49	3.36	0.93	34.62	145.72
	Halifax	81342.14	152.13	303.76	4.33	1.04	34.62	123.47
Processing Sub-total								
West Coast	Vancouver	77561.21	175.71	456.52	5.78	1.37	29.47	134.24
Prairie	Calgary	71834.13	188.60	584.28	6.28	1.78	28.87	173.17
	Winnipeg	77359.77	196.57	712.71	11.21	1.95	20.95	173.17
Central	Toronto	79876.36	190.75	220.51	4.78	1.15	36.88	121.82
East	Montreal	86148.51	190.32	330.32	4.53	1.27	40.77	166.12
	Halifax	86219.04	191.50	327.59	5.50	1.39	40.77	143.87
TOTAL								
West Coast	Vancouver	79237.89	191.77	474.46	7.30	1.75	37.08	146.94
Prairie	Calgary	73510.81	204.66	602.22	7.80	2.16	36.48	185.87
	Winnipeg	79036.45	212.63	730.65	12.73	2.33	28.56	185.87
Central	Toronto	81553.04	206.81	238.45	6.29	1.53	44.50	134.52
East	Montreal	87825.18	206.38	348.26	6.04	1.65	48.38	178.82
	Halifax	87895.72	207.56	345.53	7.02	1.76	48.38	156.57

APPENIDX B
COMPARISON OF ATMOSPHERIC EMISSION ESTIMATES FOR CEMENT MANUFACTURING

Table B.1
COMPARISON OF ATMOSPHERIC EMISSIONS DUE TO MANUFACTURING OF CEMENT

		CO_2	Pyropr SO_2	SO_2	SO_2	NO_x	NO_x	VOC	CO	TPM
		t/t of cement	g/t of cement correct.	g/t of cement correct.	g/t of cement calc.f. energy	g/t of cement correct.	g/t of cement calc.f. energy	g/t of cement	g/t of cement	g/t of cement
Model										
West Cst	Vanc.	0.8273	472.12	1530.88	2492.31	4871.64	997.94	7.97	188.15	483.06
Prairies	Calgary	0.7344	507.45	1670.77	1671.45	5897.38	691.39	6.96	52.71	938
	Winnipg	0.7344	507.45	1670.77	1671.45	5897.38	691.39	6.96	52.71	938
Central	Toronto	0.8562	578.68	1716.75	4302.14	2120.21	1256.23	8.01	273.95	340.32
East	Montrea	0.9245	584.67	1720.87	6477.50	3305.19	1373.03	10.45	280.31	863.23
	Halifax	0.9245	584.67	1720.87	6477.50	3305.19	1373.03	10.45	280.31	603
Canadian Data[a]										
Ontario	1987	1.2540			4244.56		1351.66	7.62	186.49	340.32
Quebec	1991	0.7672			4787.25		1750.55	4.46	304.92	863.23
Quebec	1985				5901.41		1637.36	11.78	298.07	1510.9
B.C.	'91/'92		18.5-1351			1295-2868				
B.C.	1985				4175.13	3961.99		26.17	2309.12	483.06
B.C.	1987		448.02			604.77			0.00	4632.3
Other Data[b]										
Germany			555.00			1850.00				157.25
Holderbank	PC/PH		185-1110			740-2775				
	dry/wet					1850-8325				
Radian	PC/PH					1250-4800				
	dry/wet					1830-8325				
EUR sp.			555-1665			1665-2590				
EPA			1900							

Note: Most of the quoted sources cite emissions per tonne of clinker. Those figures were multiplied by 0.925 to get an approximate number per tonne of cement.

a. *Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993).
Information from Ontario Ministry of the Environment and Energy, E. Piché, 4/30/93, *Summary of Point Source Emissions from Cement & Concrete Industry (1987) — Tentative*.
Information from Ministère de l'Environnement duQuébec, R. Brulotte, 5/6/93.
Information from Environment Canada, Pacific and Yukon Region, M.D. Nassichuk, 3/31/93.
Residual Discharge Information System (RDIS), (Environment Canada).

b. *Present and Future Use of Energy in the Cement and Concrete Industries in Canada* (Holderbank Consulting Ltd., prepared for Energy, Mines and Resources Canada, Ottawa, DSS No. 23440-1-0464, March 1993).
P.B. Nielsen, *SO_2 and NO_X Emissions from Modern Cement Kilns with a View to Future Regulations*, (ZKG, No. 9/91, pp.449-456, Trans. No.11/91), pp.235-239.
A.T. Queen et al, *Cement Kiln NO_X Control*, (Proc. 1993 IEEE Cement Industry Technical Conference, Toronto, May 1993).
Residual Discharge Information System (RDIS) (Environment Canada).