Watching our Waste

A National Construction Waste Analysis In Canada

Using LEED™ Certified Project Data

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Wood Waste: Image courtesy of [Jon Sailer]

Light House would like to thank the National Zero Waste Council, Metro Vancouver, the Canada Green Building Council, Lafarge Canada Inc., Recollective Consulting and Ledcor for their contributions to this report.

Contents

Introduction:

For more than 15 years, the Canada Green Building Council (CaGBC) has certified building projects across Canada under the LEED (Leadership in Energy and Environmental Design) rating system. As part of this process, they have collected construction and demolition (C&D) waste data from a wide variety of projects. This includes new builds and major renovations of commercial, multi-unit residential, industrial, and institutional projects.

Of the approximately 1,000 projects that the CaGBC has certified under LEED Canada 2009, 690 had sufficient waste data to analyze. This represents one of the largest datasets of construction waste currently available[1] and is a significant sampling of construction projects. With this sampling, we have estimated the excess materials generated per square meter of constructed space. We hope the information in this report and the construction waste database can help those in design, construction and government better understand the flow of materials in the industry, and how to prevent the waste of these materials.

Accurate information on the composition and quantity of construction waste is important for policymakers, designers, builders and those responsible for the management of recycling and waste facilities. Although we use the phrase 'construction waste' as an industry standard, we also use the term 'excess materials' – this term better represents the resource flow from construction projects, where only a portion of this excess is actually waste.

Methodology

Projects pursuing LEED certification will commonly (greater than 90%) target the credit for Construction Waste Management. The intent of the Construction Waste Management credit is:

> "To divert construction and demolition debris from disposal in landfills and incineration facilities. Redirect recyclable recovered resources back to the manufacturing process and redirect reusable materials to appropriate sites."

This credit requires the tracking of excess materials that leave the site and materials reused on site, excluding excavated soil, land-clearing debris and hazardous materials, and recording the ultimate destination of that material. The materials are categorized as diverted if they do not end up in landfill, or incinerated. The project is rewarded one "point" under the rating system for diverting 50% of waste by volume or weight, a second point for diverting 75%, and is eligible

[1] Many construction waste statistics are generated from information gathered from receiving facilities or are based on estimates, as opposed to the recording of waste from construction projects. To the best of our knowledge this is the largest number of projects contributing to any one database of construction and demolition waste.

for a third point under the *Innovation* section of LEED for “exceptional performance” if 95% or more of the waste is diverted. The credit requires that the project report on the waste from any demolition within the project boundaries, but some projects begin after demolition has occurred or are on sites without buildings, so there’s a mix of both new construction and demolition waste reported.

Limitations

Although the data is extensive, it is important to recognize its limitations. The following identifies the characteristics of the information available in the dataset:

- The projects are industrial, commercial, institutional (ICI) and multi-unit residential buildings (MURBs). Single occupancy dwellings and low-rise residential projects (Part 9 of the National Building Code) are not represented.
- “Minor” renovation projects are not included in the data, “major renovations”[2] of existing buildings are.
- The geographic distribution of LEED projects is not representative of the distribution of construction in general. There are higher numbers of LEED projects in jurisdictions that mandate or promote green building certifications, and urban centres with larger populations are disproportionately represented due to market and other influences.
- Although most regions in Canada have LEED certified projects, in some, the sample size is too small to draw conclusions about that region. Where appropriate, we have provided the number and type of projects that contribute to any results that we have presented.
- “Core and shell” projects, defined by the CaGBC as those projects with less than 50% of the interior space fitted out, have been excluded. We wished to obtain a complete picture of the excess materials generated by building projects, and interior walls, finishes and systems contribute to that picture.
- LEED projects do not represent *typical* rates of recycling in any region, they represent the recycling rates that are *possible* to achieve in each region. Typically, LEED projects attempt to maximize their waste diversion to the extent possible given the available infrastructure in their geographic area.
- We are not able to determine the recycling rates for individual construction materials. The manner in which the data is recorded means that much of what has *not* been diverted from landfill or incineration is simply recorded as “waste” or “commingled”, without identifying the types of materials the waste is composed of.

[2] “A “major renovation” to an existing building includes extensive alteration work in addition to work on the exterior shell of the building and/or primary structural components and/or the core and peripheral MEP (mechanical – electrical – plumbing). Typically, the extent and nature of the work is such that the primary function space cannot be used for its intended purpose while the work is in progress and where a new certificate of occupancy is required before the work area can be reoccupied.” – LEED Canada Reference Guide for Green Building Design and Construction 2009

- Projects will generate excess materials over their entire construction. We do not know the period of construction so have attributed the waste generated to the completion date.
- **Demolition or new construction waste is not identified as such in the data**. Some LEED projects exclude the demolition of existing buildings on the site, or have no existing buildings being demolished. For exclusion, the demolition must be outside of the project construction contract.
- All data is as reported by the project teams in their first submission for certification, prior to the CaGBC's review. The only changes to this data are those noted under "Corrections and Alterations".

Corrections and Alterations

Not all information fields were filled in for every project in the database. Some were missing dates, costs, and floor area, and some waste entries were obviously incorrect. We made the following adjustments to the data:

- If the project completion date was missing, and we were able to find the certification date, we replaced the completion date with the certification date less 18 months to account for the time for the LEED submission and review. Projects can take between approximately 6 months to several years to certify. Where we could not find a certification date, we excluded these projects from any "trends" results.
- For comparison to Statistics Canada construction costs, we have taken the lowest and the highest cross-Canada construction cost estimates per building type from the *2018 Canadian Construction Cost Guide* by Altus Group (Altus 2018). This provides a range for national waste and GHG emissions estimates.[3].
- Projects without a gross floor area entered were excluded from calculations yielding weight or volume of excess materials per area.
- If the waste data appeared to be three orders of magnitude (1,000 times) higher than typical, we assumed kilograms had been entered as tonnes, and changed the entries accordingly.

The result of these exclusions is that the total waste will vary for each calculation, depending on whether the calculation is by cost, area, or by year produced. All changes to the original data have been logged and will be released with the database.

[3] Please see Appendix C.

The Big Picture, A National Perspective

The Quantity of Construction Waste in Canada

The following is an estimate of the excess materials (construction "waste") generated per square meter of gross floor area (GFA) based on 678 projects totalling 7,365,149m^2 constructed from 2004 to 2020.

Table 1: Excess Materials per Gross Floor Area, National
For Industrial, Commercial, Institution and Multi-unit Residential

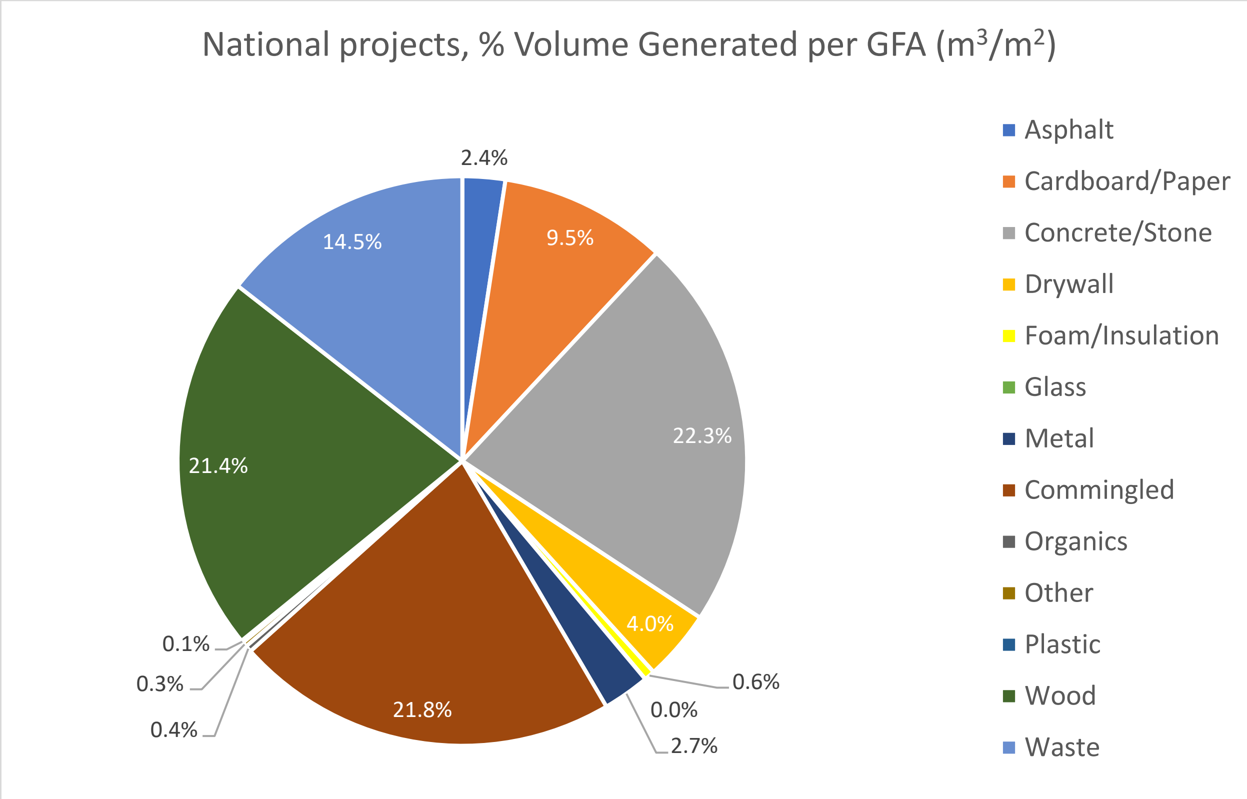
Material	Weight Generated[4] per GFA (kg/m^2)	Percentage Total by Weight	Volume Generated[5] per GFA (m^3/m^2)	Percentage Total by Volume
Asphalt	4.65	3.8%	0.01084	2.4%
Cardboard/Paper	2.52	2.1%	0.04214	9.4%
Concrete/Stone	50.20	41.3%	0.10119	22.7%
Drywall	5.30	4.4%	0.01770	4.0%
Foam/Insulation	0.08	0.1%	0.00269	0.6%
Glass	0.03	0.0%	0.00002	0.0%
Metal	7.04	5.8%	0.01180	2.6%
Commingled[6]	20.18	16.6%	0.09661	21.6%
Organics	0.24	0.2%	0.00162	0.4%
Other	0.25	0.2%	0.00121	0.3%
Plastic	0.80	0.7%	0.00159	0.4%
Wood	17.00	14.0%	0.09505	21.3%
Waste	13.38	11.0%	0.06403	14.3%
Totals:	**121.66**	**100%**	**0.44649**	**100%**

[4] Please see Appendix D for total weights of each excess material.

[5] Please see Appendix B for weight to volume conversion for each excess material.

[6] Commingled represents loads of mixed waste which can include wood, metal, concrete, drywall and other common construction materials. Usually only a portion of this material is recycled.

Chart 1: Excess Materials Volume Generated per Gross Floor Area, National
For Industrial, Commercial, Institution and Multi-unit Residential



By weight, concrete is the largest contributor at 41.3 % of the total, followed by commingled and waste (27.59% combined) and wood at 17%. Volume estimates tell a different story, with commingled and waste combined at 36%, concrete at 22.7% and 21.3% for wood. Where single waste streams are reported, indicating separation of materials on the construction site, there are generally very high diversion rates. Where the waste is mixed or "commingled" on site, and separated at off-site recycling facilities, the diversion rates are generally much lower. If the levels of contamination by other materials or waste exceed the recycling facilities' allowable limits, entire containers of materials can be rejected and disposed of.

The Impact of Construction Waste in Canada

What do these materials represent in terms of costs to owners, and greenhouse gas emissions to the environment? The table below shows an estimate of the project construction costs for each building type, and their associated construction waste:

Table 2: Construction Costs Estimates and Waste by Building Type, All LEED Certified Projects

Building Type[7]	Total Construction Costs[8]		Total Waste Generated[9] (kg)
	Low Estimate	High Estimate	
Industrial	$510,349,923	$3,147,157,859	75,991,918
Commercial	$2,737,570,326	$6,888,080,176	181,793,505
Institutional	$4,910,374,017	$15,191,469,615	445,514,470
Residential (MURBs)	$3,811,453,268	$7,847,109,670	192,770,171

Using Statistics Canada data on expenditures on construction for non-residential buildings, we see the following:

Table 3: Statistics Canada Capital Expenditures, Non-residential Building Construction

Year:	**2014**	**2015**	**2016**	**2017**	**2018**
Type of asset	Dollars, In Millions				
Non-residential building construction	*45,373.50*	*48,243.20*	*43,939.00*	*45,167.50*	*52,482.40*
Industrial buildings	9,291.90	8,635.20	7,052.10	7,175.50	10,481.60
Commercial buildings	21,916.80	23,498.30	21,425.60	21,114.30	24,643.50
Institutional buildings	14,164.90	16,109.70	15,461.30	16,877.70	17,357.30

(StatCan n.d.)

Applying our waste generation per cost to the 2018 expenditures on ICI construction provides the following results:

Table 4a: Total Construction Waste Generation for ICI Buildings, 2018

Building Type	Waste kg/$100		2018 Cost ($M)	2018 Waste (tonnes)	
	Low Cost Est.	High Cost Est.		Low Cost Est.	High Cost Est.
Industrial	14.89	2.41	10,481.6	1,560,727	253,091
Commercial	6.64	2.64	24,643.5	1,636,498	650,403
Institutional	9.07	2.93	17,357.3	1,574,815	509,031
Total			**52,482.4**	**4,772,039**	**1,412,525**

The 2018 estimate for annual waste generation for industrial, commercial and institutional new construction and major renovations is **from 1.41 to 4.77 million tonnes**. Keep in mind that this figure does not include all demolition waste and excludes all residential construction. A lower

[7] Please see Appendix A for additional information on Building Types
[8] Please see Appendix C for construction cost estimations of four building types.
[9] Total waste generated from 678 LEED certified projects which has the same summation from Appendix D.

construction cost per constructed floor area will exaggerate the amount of waste, and higher construction costs per area will underestimate the waste.

The typical excess material types by building type are as below:

Table 4b: Construction Waste by Material Type and Building Type, National[10]

Material	Commercial		Industrial		Institutional		Residential (MURBs)	
	% by Weight	% by Volume	% by Weight	% by Volume	% by Weight	% by Volume	% by Weight	% by Volume
Asphalt	3.5%	2.4%	5.4%	2.8%	4.6%	3.0%	1.6%	1.0%
Cardboard/Paper	1.8%	9.0%	4.8%	18.2%	1.3%	6.3%	2.9%	12.5%
Concrete/Stone	51.4%	30.3%	21.1%	9.4%	42.4%	23.7%	38.9%	19.9%
Drywall	2.8%	2.8%	9.2%	6.9%	2.5%	2.3%	8.1%	7.0%
Foam/Insulation	0.1%	0.9%	0.0%	0.1%	0.1%	0.5%	0.1%	0.9%
Glass	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Metal	5.8%	2.9%	7.1%	2.7%	5.3%	2.5%	6.1%	2.6%
Commingled	14.4%	20.5%	8.1%	8.7%	24.1%	32.7%	4.1%	5.1%
Organics	0.1%	0.2%	0.0%	0.1%	0.3%	0.6%	0.1%	0.1%
Other	0.1%	0.1%	0.5%	0.5%	0.2%	0.3%	0.2%	0.2%
Plastic	0.7%	0.4%	0.7%	0.3%	0.4%	0.2%	1.2%	0.6%
Wood	11.6%	19.4%	21.6%	27.1%	10.0%	15.8%	22.0%	31.8%
Waste	7.7%	10.9%	21.6%	23.2%	8.8%	11.9%	14.8%	18.3%

Carbon Emissions

Embodied carbon is the carbon that is required to produce a material or product. Excess materials that go to waste on construction sites do not fulfil their intended use. Similarly, materials from demolition that cannot be recovered and reused for their original purpose, or a better use are also “wasted”. The embodied carbon associated with the extraction or harvesting and manufacturing of these materials, or the replacement materials for unrecovered demolition, could have been avoided. With the total ICI construction waste estimate per year and the percentages above we can estimate the greenhouse gas (GHG) emissions, or embodied carbon, based on the avoidance of new resource use, or “source reduction” for the materials identified. Using the US Environmental Protection Agency’s (EPA) WARM[11] tool, we have matched the following CO_2e emission factors to the materials:

[10] Please see Appendix B and Appendix D.

[11] EPA Waste Reduction Model Tool: WARM version 15, updated November 2020

Table 5a: CO_2e Emissions per tonne NEW Material

Material	Method	$MTCO_2e$/ tonne	EPA Description
Asphalt	WARM	0.12	Asphalt Concrete
Cardboard/Paper	WARM	6.15	Corrugated Containers
Concrete	EPA2006[12]	0.13	Concrete
Drywall	WARM	0.24	Drywall
Insulation	WARM	0.42	Fiberglass Insulation
Glass	WARM	0.58	Glass
Metal	WARM	1.84	Structural Steel
Organics	WARM	0.06	Yard Trimmings
Plastic	WARM	2.06	Mixed Plastic
Wood	WARM	2.35	Dimensional Lumber

Table 5b: ICI Excess Material "Source Reduced" CO2e Emissions Based on 2018 Construction Estimate

Excess Material	Low Weight Est. (tonnes)	High Weight Est. (tonnes)	$MTCO_2e$/ tonne	Low $MTCO_2e$ Estimate	High $MTCO_2e$ Estimate
Asphalt	59,846	213,998	0.12	7,182	25,680
Cardboard/Paper	30,473	124,844	6.15	187,409	767,791
Concrete/Stone	603,538	1,838,195	0.13	78,460	238,965
Drywall	54,221	228,779	0.24	13,013	54,907
Foam/Insulation	1,159	3,211	0.42	487	1,349
Glass	650	1,636	0.58	377	949
Metal	82,671	289,194	1.84	152,115	532,117
Commingled	236,835	741,605			
Organics	2,177	6,361	0.06	131	382
Other	2,934	12,590			
Plastic	8,361	28,680	2.06	17,224	59,081
Wood	181,017	684,432	2.35	425,390	1,608,415
Waste	149,543	601,711			
Total	**1,413,428**	**4,775,237**		***881,786***	***3,289,635***

Our estimate of GHG emissions for source reduction based on construction costs of industrial, commercial and institutional construction for 2018 is between 0.88 and 3.29 million $MTCO_2e$, with wood waste (highlighted in the table) accounting for nearly half of this total. *Commingled, Other* and *Waste* are not included in this total, but contribute just under 30% to construction

[12] The WARM v15 calculator does not have an entry for concrete source reduction, the EPA 2006 estimate of CO_2e for concrete (Bowyer n.d.) was aligned with other sources such as the ATHENA Life Cycle Assessment tool, and the National Industrial Symbiosis (NISP) calculator.

waste. Based on a weighted average of 0.811 $MTCO_2e$/ tonne for 'known' materials, this would account for another 0.32 to 1.10 million $MTCO_2e$. **This brings our 2018 GHG emissions estimate to between 1.20 to 4.39 million $MTCO_2e$** for resource reduction for ICI construction only. This figure is for the avoidance of new material use – our practices of constructing buildings largely on site mean that some of this waste is currently inevitable. This total does not include the GHG emissions associated with disposal in landfill or incineration of these materials, and while the LEED projects investigated diverted a total of 88% by weight of their construction waste, this rate is much higher than the 16% diversion rate reported for 2015 (CCME 2019). In this regard, the total GHG emissions for the source reduction *and* landfilling would be greater than the emissions reported here.

Material Costs

All building materials were originally paid for by the building owner – consequently any excess materials represent unnecessary costs. For every square meter of constructed space, just over 120kg (or $0.44m^3$) of wasted material is generated (see Table 1). What might this material have cost the owner to purchase? The cost of the items included in each material category will vary greatly – from dimensional lumber to interior woodwork for example, and while an in depth analysis of the specific waste from any particular project would be needed to determine the "real costs", we can estimate what the avoided costs *might* be for some of those categories.

Table 6: Cost of Materials Wasted per Gross Floor Area

Materials	**Waste/m² GFA**	**Cost/Unit NEW Material**	**Cost/m2 GFA**
Asphalt	$0.0107m^3$	$105.00/m³	$1.12
Concrete/Stone	$0.09839m^3$	$157.50/m³	$15.50
Drywall	5.3kg	$2.75/kg	$14.58
Metal	7.04kg	$5.50/kg	$38.72
Wood	17kg	$1.75/kg	$29.75
Total Cost/m²:			**$99.66**

Current construction practices make some of these wastes unavoidable, but **the cost of these unutilized materials is just under $100/m² of gross floor area. The total costs that could have been avoided for unutilized materials in ICI buildings based on 2018 construction expenditures is $1.12 to $4.04 *billion*.**[13]

[13] Refer to Appendix E.

Trends in LEED Construction Recycling Rates

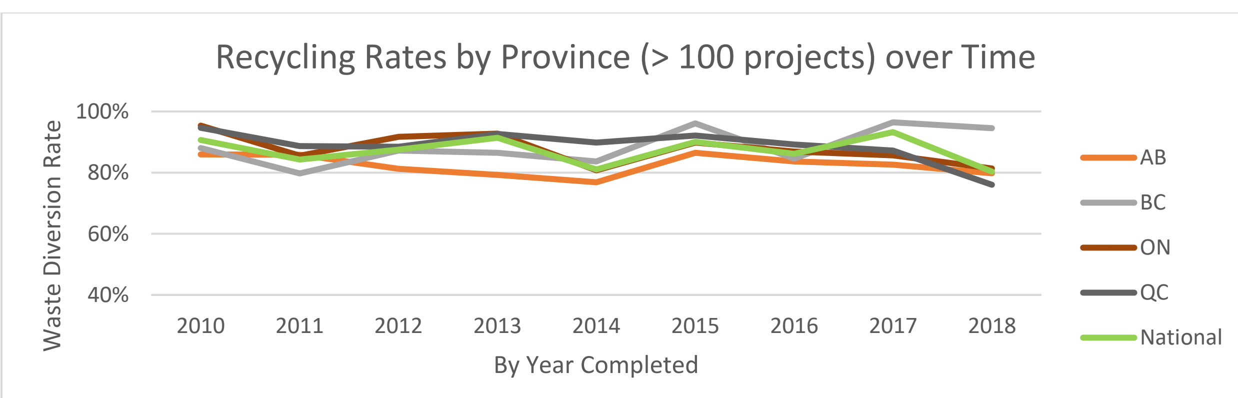
Table 7 shows the overall recycling rates for the LEED certified projects in each province and territory over the decade from 2009 to 2019.

Table 7: Diversion Rates by Province/Territory by Year from 2009 to 2019

Province/ Territory	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total	# of Projects
	% recycled by weight												
AB		85.9%	85.8%	81.3%	79.3%	76.8%	86.5%	83.6%	82.6%	79.7%		83.3%	159
BC	73.7%	88.0%	79.7%	87.2%	86.4%	83.6%	96.1%	84.6%	96.4%	94.6%		90.9%	127
MB		78.8%	92.0%	53.9%	91.2%	72.3%	77.3%	80.7%	95.2%		87.5%	88.5%	28
NB						72.2%	90.7%		86.6%			78.3%	3
NL						78.7%						78.7%	1
NS		86.8%	88.5%	81.7%	91.3%	96.5%		84.8%				85.2%	15
ON	65.2%	95.4%	85.5%	91.6%	92.7%	80.7%	89.8%	86.8%	85.6%	81.3%		87.6%	179
QC		94.6%	88.7%	88.5%	92.7%	89.8%	92.2%	89.2%	87.2%	76.0%	98.1%	90.1%	134
SK			75.3%	82.8%	68.5%	70.0%	94.1%	76.9%				80.5%	20
YK						65.2%						65.2%	1
National	73.7%	90.7%	84.3%	87.5%	91.4%	81.0%	90.0%	86.1%	93.2%	80.3%	87.5%	88.0%	667

Looking at this information graphically we find that there's insufficient data to determine trends by region. Even taking the provinces with more than 100 certified projects (see graph below) doesn't offer any insights, other than there has not been a statistically significant change over that time period in projects that are achieving a high rate of recycling, remembering that these rates are not average for the construction industry, but of LEED certified projects, representing higher environmental performance.

What this information *does* tell us is that **diversion rates significantly higher than the estimated 16% (CCME 19) currently being achieved are possible, and have been for over a decade**. In fact, it is possible to invert that diversion rate, as evidenced by the overall 88% diversion achieved by the 678 LEED projects across the country, in both urban and rural locations.



A Regional Example: Metro Vancouver & British Columbia

Metro Vancouver

Of the national dataset, 102 projects were located in the Metro Vancouver region, they are comprised of the following building types:

Table 8a: Metro Vancouver Projects by Building Types[14]

Building Type	Gross Building Area (m^2)	Number of Projects
Assembly	42,344	10
Commercial	67,614	12
Educational	103,510	11
Industrial	107,756	10
Institutional	19,920	4
Other	207,212	6
Residential (MURBs)	523,875	41
Retail	33,970	3
Treatment/Care	89,789	5
Totals:	**1,195,990**	**102**

Cumulatively, these projects generated **116,172 tonnes** of excess materials with **84%** of this material diverted from landfill or incineration. LEED data often excludes demolition of the existing building(s) on the project site and is comprised primarily from the construction of new buildings or the complete renovation of existing buildings (see "*Limitations*"). *Table 8b* shows the types and quantities of excess materials generated by the Metro Vancouver projects:

[14] Please see Appendix A for additional information on Building Types

Table 8b: Metro Vancouver Projects – Excess Materials[15]

Material	Weigh (kg)	% by Weight	Volume (m^3)	% by Volume
Asphalt	2,819,257	2.4%	6,483	1.6%
Cardboard/Paper	1,519,582	1.3%	25,326	6.2%
Concrete/Stone	50,593,710	43.6%	99,161	24.4%
Drywall	6,167,390	5.3%	20,558	5.1%
Foam/Insulation	6,450	0.0%	215	0.1%
Glass	29,000	0.0%	23	0.0%
Metal	7,803,190	6.7%	13,005	3.2%
Commingled	8,184,247	7.0%	38,973	9.6%
Organics	104,238	0.1%	703	0.2%
Other	417,516	0.4%	2,011	0.5%
Plastic	40,854	0.0%	82	0.0%
Wood	21,719,360	18.7%	120,663	29.6%
Waste	16,766,808	14.4%	79,842	19.6%

[15] Please see Appendix B for weigh to volume conversion

Chart 2

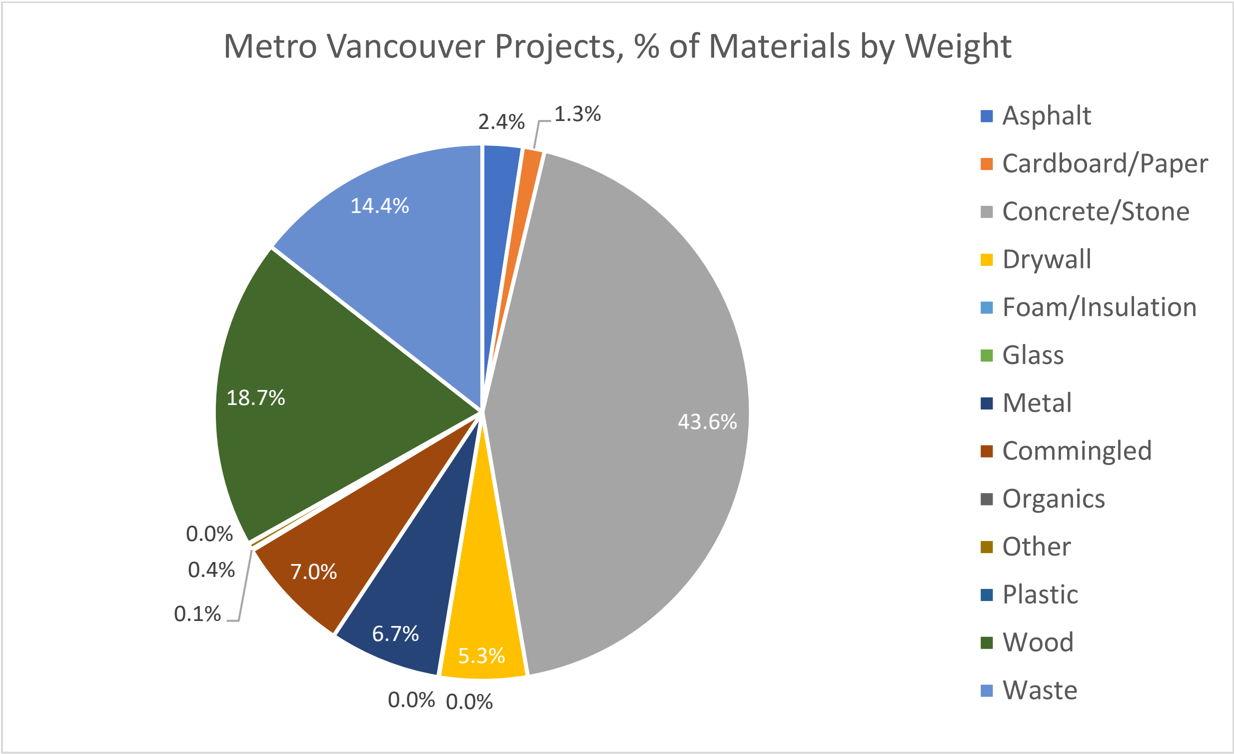
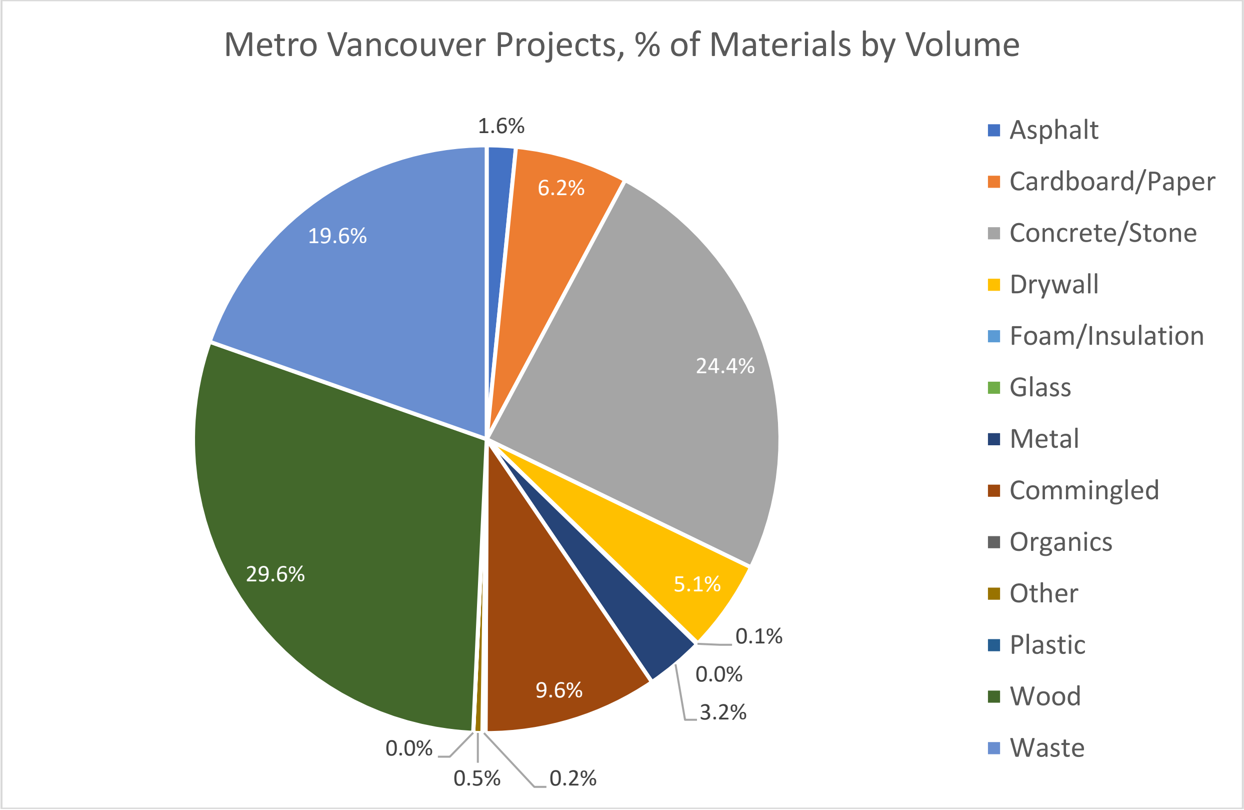


Chart 3



While this data gives an indication of the composition of the construction waste generated, the categories of commingled and waste (just over 21% by weight and 29% by volume) remain undescribed. If we assume that these two categories are consistent with the construction waste that is generated in Metro Vancouver based on the *2018 Construction & Demolition Waste Composition Study* (TRI 2019) we can estimate the total amounts of each type of material generated. When aligning the 17 categories of the waste composition study with the LEED material categories of the LEED project database, we obtain the following for construction and demolition landfill waste within the region.

Table 9: Metro Vancouver C&D Waste Composition By Material

Material	% by Weight
Asphalt	4.9%
Cardboard/Paper	1.6%
Concrete/Stone	1.4%
Glass	1.8%
Metal	4.2%
Organics	0.5%
Other	11.9%
Plastic	11.5%
Wood	60.8%
Waste (household garbage)	1.5%

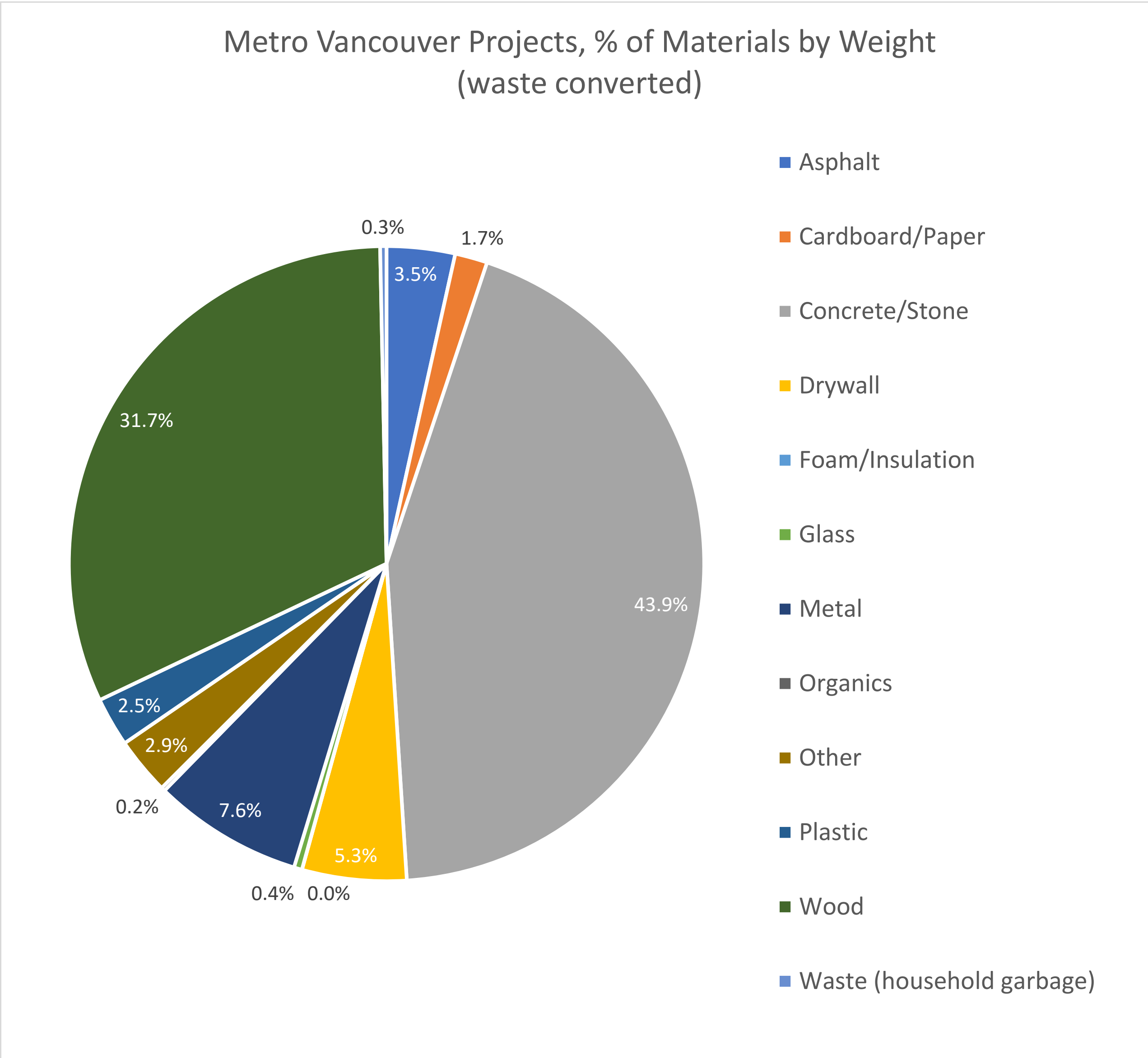
Multiplying these percentages by the Commingled and Waste categories, we obtain the following composition:

Calculation: Material % by Weight x (Total Commingled + Waste) (kg) = Additional Material Waste (kg)

Table 10: Metro Vancouver Projects within LEED Database– Commingled and Waste converted to Materials

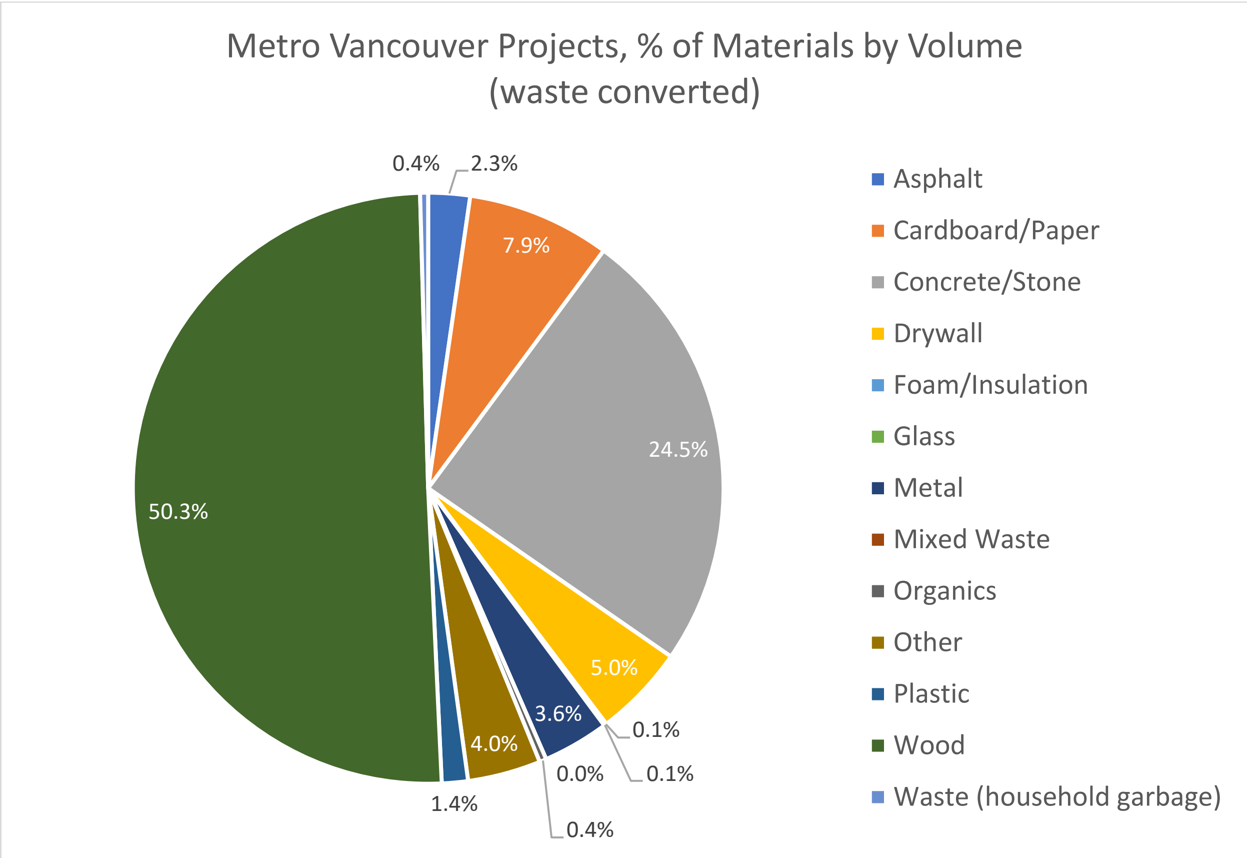
Material	Weight (kg)	% by Weight	Volume (m3)	% by Volume
Asphalt	4,040,637	3.5%	9,292	2.3%
Cardboard/Paper	1,918,400	1.7%	31,973	7.9%
Concrete/Stone	50,942,676	43.9%	99,845	24.5%
Drywall	6,167,390	5.3%	20,558	5.0%
Foam/Insulation	6,450	0.0%	215	0.1%
Glass	477,670	0.4%	373	0.1%
Metal	8,850,088	7.6%	14,750	3.6%
Commingled	0	0.0%	0	0.0%
Organics	228,869	0.2%	1,543	0.4%
Other	3,383,725	2.9%	16,296	4.0%
Plastic	2,907,359	2.5%	5,819	1.4%
Wood	36,874,447	31.7%	204,858	50.3%
Waste (household garbage)	373,892	0.3%	1,780	0.4%

Chart 4



There are limitations to this assumption. The waste composition study will include C&D waste from single family dwellings – this building category is not included in the LEED project database. This will likely exaggerate the amount of wood as home construction and demolition have higher quantities of lumber per square meter of constructed space than ICI or MURB construction due to wood being the structural material of choice, rather than steel and concrete, for single family dwellings, and the higher building envelope to floor area ratios.

Chart 5



It is important to recognize that this represents excess materials, and that 88% was diverted from landfill/incineration on the LEED certified projects analyzed in this study. As mentioned in *Limitations*, it is not possible to determine the recycling rates for each type of material with the data on hand because the commingled and waste categories contain multiple material types, and these materials are not identified within commingled/waste by weight or volume. *Chart 5* demonstrates that by volume, wood represents the single largest type of excess material on these projects.

Vancouver, Recycling Case Study

Taking one example from the Metro Vancouver dataset of a two-storey 576m^2 restaurant project in Vancouver, we can compare the costs for recycling versus disposal of the construction and demolition waste. The project achieved a 99% waste diversion rate. Below is the waste composition and cost comparison:

Table 11: Case Study Comparison of Recycling vs Disposal Costs[16] [17]

Type of Waste	Amount of Waste (kg)	Costs ($) to reuse/recycle	Cost ($) to dispose	Source for Costs
Garbage	10,396	936	936	CoV (2020)
Concrete	1,082,000	0	3,246	CoV (2020)
Metal	22,282	(16,000)	0	CoV (2020) Avada (2018)
Wood	66,358	5,309	5,309	CoV (2020)
Cardboard	4,920	0	445	CoV (2020)
Asphalt	38,600	115	5,327	CoV (2020) Ecowaste Industries Ltd. (n.d.)
Totals	1,224,556	**Revenue $9,640**	**Cost $15,263**	**$24,903 Difference**

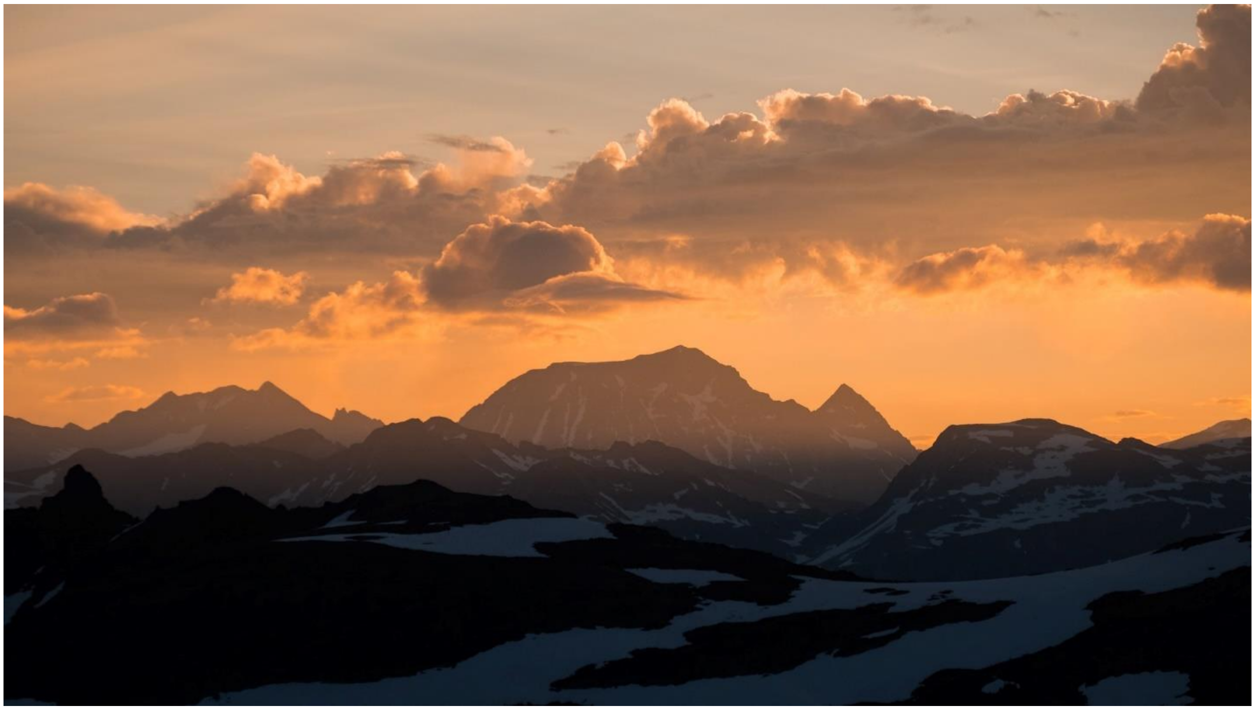
Modified from Source: (McGratten 2020)

Source separation and recycling waste on this project represent a potential savings of $24,903 over the cost of disposal (resulting in a net revenue of $9,640). Salvage would further increase these savings. The savings typically offset the additional labour costs of source separation.

[16] These costs are based on 2020 disposal and recycling fees for the City of Vancouver, not the actual costs/revenue of the project which are unknown.

[17] The interior finishes of the restaurant were primarily wood, there was negligible drywall / gypsum waste generated.

Whistler Case Study



Whistler, Photo by Spencer Watson

Looking at best practices in different jurisdictions, we find some examples where everything falls into place. One such example is in Whistler, British Columbia where the *Re-Build-It Centre* and *Re-Use-It Centre* help to put a greater dent in waste than is merited by the size of these facilities. Operated by the *Whistler Community Services Society*, the *Re-Use-It Centre* generates more than 100 times the revenue per capita as popular building product reuse centres in Vancouver, with a fraction of the floor space (CCME 2019). What makes the *Re-Use-It* and *Re-Build-It Centres* so effective? A combination of characteristics contribute to the enterprise's success, and the corresponding diversion of construction and demolition waste:

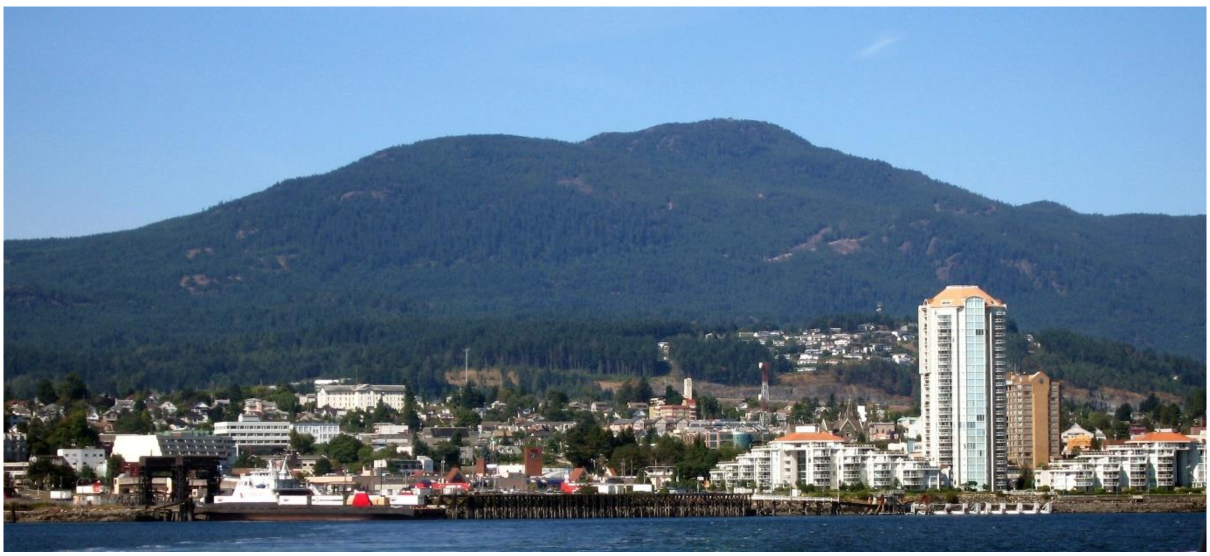
- The operator, the *Whistler Community Services Society*, is a non-profit which enables it to give tax receipts for larger donations of goods and building materials. The revenue from the society directly benefits the community and funds services, providing residents with an incentive to both donate and purchase.
- *The Re-Use-It Centre* is located adjacent to the recycling depot. This location means that residents can conveniently drop off their donations, and shop, when they recycle - Whistler does not have curbside recycling so the traffic to this location is very high.
- *The Re-Build-It Centre* is also the home of Whistler's only Tool Library. This increases the number of residents who can take advantage of the surplus and used building

supplies offered at the Centre. Re-use or upcycling of building components represents the "highest and best use" of these materials.

The co-location of building product reuse centres with recycling depots, waste disposal and transfer facilities – creating a "reuse & recycling" hub – can greatly increase the amount of donations to these centres.[18]

Regional District of Nanaimo Case Study

Targeting their largest construction material waste – wood, the Regional District of Nanaimo implemented a wood waste ban in January 2008. Prior to this, the district developed a "Waste Stream Management Licensing System" in collaboration with private sector, specifically waste haulers, builders (wood waste generators) and private processing facilities. The program had no capital costs for the District as the private sector provided the investment in the recycling infrastructure necessary for the clean wood waste processing. The private sector was supportive of the ban and the licensing system as it provided local economic opportunity.



Nanaimo, British Columbia

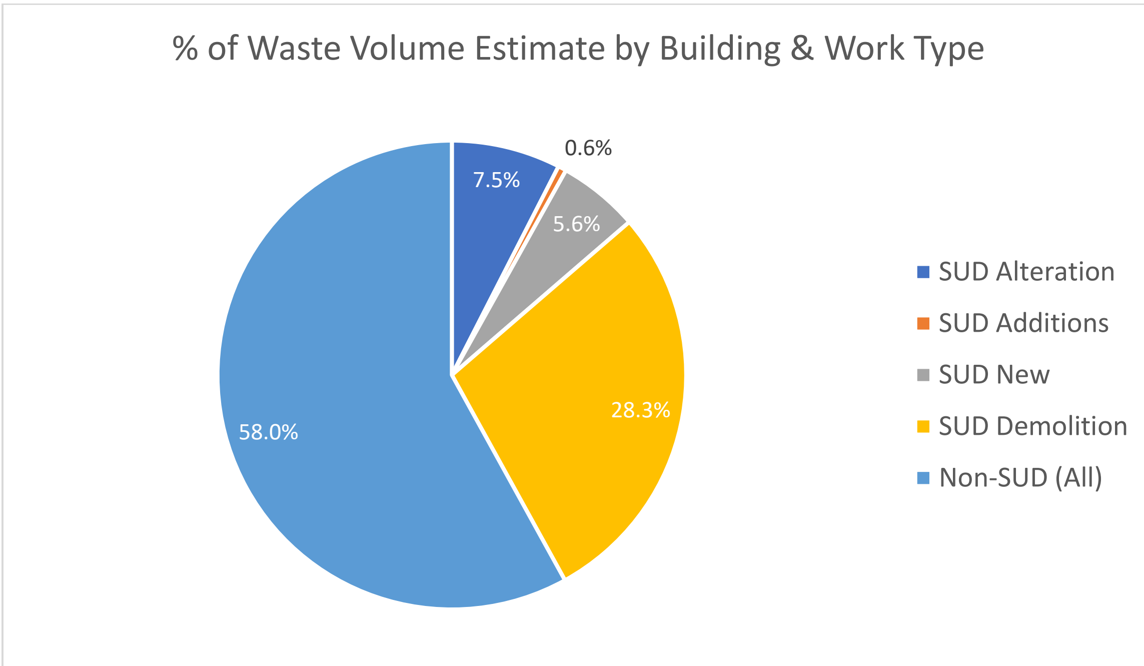
These measures reduced the amount of wood waste by 87%, from 8,000 tonnes of wood waste disposed of in 2006 to 1,000 tonnes of 'dirty' wood waste in 2008, which was ground up and used as landfill daily cover. The inability to site a new landfill provided the incentive to the District and its private sector partners to find solutions to the issue of wood waste (RDN).

[18] Source: David Van Seters, Sustainability Ventures, Vancouver, BC, http://sustainabilityventures.ca/ as described in CCME 2019.

District of Squamish Case Study

> "Canada has 3 cities with more than a million people, 51 cities with between 100,000 and 1 million people, and 235 cities with between 10,000 and 100,000 people."[19]

At a population of approximately 20,000, the District of Squamish falls within the majority size range of cities. What can an analysis of the District's building activity tell us about the generation of construction waste in a population of this size? When the value of permits obtained in the first 10 months of 2020 are converted to typical volumes of waste generated per dollar of construction, alteration or demolition, we see the following distribution of waste by each of the permit[20] types:



Building/Work Type	**Volume (m^3)**	**% by Volume**
SUD Alteration	904	7.5%
SUD Additions	69	0.6%
SUD New	670	5.6%
SUD Demolition	3,401	28.3%
Non-SUD (All)	6,971	58.0%
Total	**12,015**	**100%**

Cost to waste conversions are not particularly accurate due to the variability of demolition costs per area of demolished space, however the above is an indication that the waste from the ICI and MURBs construction, alteration and demolition is comparable to the waste generated by

[19] https://worldpopulationreview.com/countries/cities/canada
[20] SUD stands for Single-unit Dwelling. Non-SUD refers to industrial, commercial, institution and multi-unit residential permits, of all work types – alteration, additions, new construction and demolition.

the construction, alteration and demolition of single-unit dwellings or "SUDs" and deserves the same amount of attention in terms of regulation and policy.

Conclusions and Recommendations

Conclusions

While we can celebrate the 88% diversion rate that these LEED certified projects were able to achieve, excess materials were, for the most part, "down-cycled" rather than recycled into a comparable product to the original. Structural concrete typically becomes aggregate for roadwork and fill, wood is chipped and used as mulch or as fuel. Much of the resource inputs into these materials – energy, water and human effort – are lost in this process.

Our efforts need to be directed at reducing construction waste at the source, in other words the design of our buildings and the process of constructing them. Waste occurs at the site due to our current method of constructing buildings. This waste results from the necessity to cut materials to size on location, under conditions that do not allow for the easy preservation or protection from weather, sorting, and reuse or recycling of those materials. Modular construction (in part or in whole), built in factories will vastly reduce the amounts of excess materials generated by building. We need to start "assembling" our buildings, rather than "constructing" them. Incorporating "reversible design" or "design for disassembly" will mean that we do not burden future generations with our demolition waste.

Recommendations

Changes to design and construction processes notwithstanding, we have to manage construction and demolition waste *now*. Based on the analysis of the waste of these 678 projects, we would recommend the following in order to best direct diversion efforts:

- Municipalities and regional governments can be much more demanding of builders in terms of regulating diversion rates. These projects are located in all provinces and represent both rural and urban regions. All were able to achieve at a *minimum* 50% diversion of their construction waste. There is a business case for waste diversion as demonstrated by the examples from the City of Vancouver and the Regional District of Nanaimo. Construction waste diversion targets can economically benefit both the public and private sectors.
- Regulators should set diversion targets by volume rather than weight. The lifespans of landfills are measured in terms of volume, not mass. When looked at by volume, wood becomes a more important material to divert. This also aligns well with the goal of reduction of GHG emissions by avoiding the decomposition of wood waste in landfill. It is not onerous to convert weight, which is how most waste is measured, to volume for this purpose.

- When feasible, construction waste should be separated on site, rather than commingled and sorted off-site. While there are some constricted sites where this might not be possible, source separation will lead to higher diversion rates, and the savings in cost of disposal or recycling will likely offset the additional labour cost to separate.
- Many jurisdictions regulate residential demolition waste, but not industrial, commercial and institutional construction and demolition waste. There is a significant amount of waste generated by these sectors, and very little reason not to require this waste to be diverted. LEED certified projects have demonstrated what is possible in this regard.

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APPENDIX A
Building Type Assignments

Database Entries	Building Types (National)	Building Types (Metro Vancouver)
Assembly	Institutional	Assembly
Clinic	Commercial	Commercial
Commercial	Commercial	Commercial
Community Centre	Institutional	Assembly
Community Safety	Institutional	Institutional
Daycare	Institutional	Assembly
Elementary School	Institutional	Educational
High School	Institutional	Educational
High-rise multi-unit residential (>10 storeys)	Residential (MURBs)	Residential
Hospital / Clinic	Institutional	Treatment/Care
Industrial / Manufacturing	Industrial	Industrial
K-9 School	Institutional	Educational
Laboratory	Institutional	Industrial
Lecture Hall / Classroom	Institutional	Educational
Library	Institutional	Assembly
Low-rise multi-unit residential (≤3 storeys)	Residential (MURBs)	Residential
Mid-rise multi-unit residential (>3 to ≤ 10 storeys)	Residential (MURBs)	Residential
Mixed Use Residential	Residential (MURBs)	Residential
Nursing Home	Institutional	Treatment/Care
Office building	Commercial	Commercial
Other	Commercial	Other
Public Safety	Institutional	Institutional
Residential	Residential (MURBs)	Residential
Retail	Commercial	Retail
Sports Facility	Institutional	Assembly
Warehouse	Industrial	Industrial

APPENDIX B
Weight to Volume Conversion Table

Material	m^3/kg	kg/m^3	Source	Notes/Description
Asphalt	0.0022995	434.9	EPA	Estimate 95% asphalt roofing, 5% asphalt paving
Cardboard/Paper	0.0166667	60.0	CaGBC LEED 2009 reference guide, page 390	Cardboard
Concrete/Stone	0.0019600	510.2	EPA	
Drywall	0.0033333	300.0	CaGBC LEED 2009 reference guide, page 390	Gypsum Wallboard
Foam/Insulation	0.0333333	30.0	https://www.atermit.com/upload/Expanded%20Polystyrene%20(EPS)%20Foam%20Insulation%20(density%2030%20kgm).pdf	verified as approximately average by this site
Glass	0.0007804	1,281.5	California Integrated Waste Management Board	
Metal	0.0016667	600.0	CaGBC LEED 2009 reference guide, page 390	Steel
Commingled	0.0047619	210.0	CaGBC LEED 2009 reference guide, page 390	Mixed Waste
Organics	0.0067422	148.3	EPA	Mixed Yard Waste - Uncompacted
Other	0.0048159	207.6	USGBC 2009 reference guide, page 360	Construction and Demolition Mixed Waste
Plastic	0.0020015	499.6	TRI 2019	Chlorine Plastic
Waste	0.0047619	210.0	CaGBC LEED 2009 reference guide, page 390	Mixed Waste
Wood	0.0055556	180.0	CaGBC LEED 2009 reference guide, page 390	

Priority of sources: 1) CaGBC/USGBC; 2) EPA; 3) Industry/academic sources.

APPENDIX C

Cost Estimates per Building Type

Based on the 2018 Canadian Construction Cost Guide by Altus Group

Building Type	***Lowest Estimate $/sqft***	***Highest Estimate $/sqft***	***Notes***
MURB	$170	$350	Excludes 60+ storey towers
Industrial	$60	$370	
Commercial	$155	$390	“Office Buildings” only
Institutional	$160	$495	Excludes healthcare & labs

APPENDIX D
Total Excess Materials, 678 LEED Certified Projects
(GFA: 7,365,149m²)

Material	Generated Weight (kg)
Asphalt	34,275,095
Cardboard/Paper	18,559,517
Concrete/Stone	369,717,597
Drywall	39,026,792
Foam/Insulation	594,996
Glass	193,330
Metal	51,832,511
Commingled	148,634,982
Organics	1,766,311
Other	1,857,777
Plastic	5,855,643
Wood	125,205,964
Waste	98,549,549
Totals:	**896,070,064**

APPENDIX E
ICI Estimated Unutilized Material Costs, 2018

ICI 2018 Estimated Excess Material	Low Weight Est. (tonnes)	High Weight Est. (tonnes)	Low Volume Est. (m^3)	High Volume Est. (m^3)	Cost/Unit NEW Material	Low Cost Est. ($)	High Cost Est. ($)
Asphalt	59,846	213,998	137,616	492,088	$105.00/m3	14,449,667	51,669,282
Concrete/Stone	603,538	1,838,195	1,182,934	3,602,862	$157.50/m3	186,312,181	567,450,797
Drywall	54,221	228,779	-	-	$2.75/kg	149,107,750	629,142,250
Metal	82,671	289,194	-	-	$5.50/kg	454,690,500	1,590,567,000
Wood	181,017	684,432	-	-	$1.75/kg	316,779,750	1,197,756,000
Total	-	-	-	-	-	**1,121,339,848**	**4,036,585,329**