Construction and Demolition Debris Generation in the United States, 2014
U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery
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1.0 Introduction

Construction and demolition (C&D) debris includes a variety of materials that may be generated from different sources (e.g., construction, renovation, demolition and natural disasters). The purpose of this document is to explain how U.S. Environmental Protection Agency (EPA) derived its estimate of C&D debris generation in the United States. The estimate included C&D debris generated from the construction, renovation and demolition of buildings, roads and bridges and other structures; and excluded C&D debris generated from land-clearing activity[1] or as a result of natural disasters.

EPA estimated how much C&D debris was generated in the United States by primarily using a materials flow analysis. Materials estimated through the materials flow analysis were concrete, steel, wood products, gypsum wallboard and plaster, brick, clay tile and asphalt shingles. Asphalt concrete generation was estimated using consumption data for recycled asphalt pavement (RAP) and an estimated asphalt concrete recovery rate.

By primarily using the materials flow analysis, EPA took the same approach as in the *Advancing Sustainable Materials Management: Facts and Figures 2013* report. Key methodology improvements include: the addition of fly ash to the calculation of annual concrete consumption; separation of railroad tie C&D debris generation from total C&D lumber generation; and an analysis of synthetic gypsum in C&D debris generated from drywall and plaster products. Methodology improvements, as well as newly published consumption data for 2012 and 2013, were used to revise C&D debris generation estimates previously published in the *Advancing Sustainable Materials Management: Facts and Figures 2013* report.

2.0 Construction and Demolition Debris Generation

This section includes a detailed description of the methodology used by EPA to estimate C&D debris generation and results from the analysis. The seven groups of products included in the analysis - concrete, steel, wood products, gypsum wallboard and plaster, brick and clay tile, asphalt shingles and asphalt concrete - represent the major components of the C&D debris stream. C&D debris generated from land-clearing activities or as a result of natural disasters was not included in the estimates.

To estimate C&D debris generation for concrete, steel, wood products, gypsum wallboard and plaster, brick, clay tile, and asphalt shingles, EPA chose to use a top-down estimation method developed from a materials flow analysis by Cochran and Townsend (2010). This method is similar to the method EPA uses to calculate waste generation from durable goods in municipal solid waste in its *Advancing Sustainable Materials Management:*

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[1] The materials flow analysis method, the top-down approach that is based on tabulated material consumption data and typical lifespans for material types, does not account for the debris generated in land-clearing activity. A separate methodology was not developed because of limitations associated with the multiple management options for land-clearing debris that are decentralized and not tracked, such as management at the point of generation.

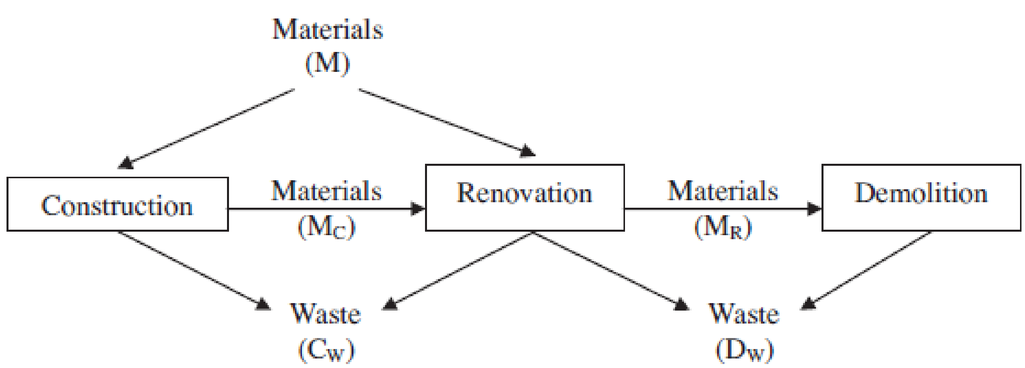
Facts and Figures reports. The materials flow method draws on publicly available historical materials-usage (consumption) data from several government and industry organizations, such as the U.S. Geological Survey (USGS) or U.S. Forest Service (USFS). Historical construction-material consumption is tabulated and typical lifespans of material types are assumed. The materials flow analysis estimates when each material has reached its end-of-life (EOL) and is ready for management.

Asphalt concrete generation was estimated using a different method. For asphalt concrete, EPA used an estimated asphalt concrete recovery rate and data on RAP consumption published by the National Asphalt Pavement Association (NAPA) and the U.S. Department of Transportation Federal Highway Administration (FHWA). The RAP data are directly related to total asphalt concrete waste generation, and no assumptions about the lifespan of asphalt concrete were required.

2.1 C&D Debris Generation Methodology

Based on the Cochran and Townsend methodology, EPA derived total C&D debris generation from the sum of waste generated during construction and demolition activities. Figure 1 depicts the flow of materials resulting from construction, renovation, and demolition over the lifetime of a building, road, bridge or other structure. Cochran and Townsend define C&D debris generated during construction (C_w) as the portion of purchased construction materials that are not incorporated into the actual structure, such as scraps and surplus materials. New construction and the installation phase of renovation projects both contribute to waste generated during construction. All of the materials (M) are consumed in construction (M_C) or renovation (M_R) becoming part of the structures that will eventually be demolished. Demolition waste (D_w) is the sum of materials removed from a structure during renovation and the materials generated from a structure's final demolition.

Figure 1. Materials Flow Diagram for Construction, Renovation, and Demolition



Source: Cochran and Townsend (2010)

Construction guides, used by builders to estimate the amount of materials to purchase for a construction project, provide the average amount of waste expected during construction for a range of materials. Cochran and Townsend used these guides to estimate the average percentage of materials discarded during construction, shown in Table 1. Equation 1 below shows the calculation of waste during construction for a given year based on annual material consumption and average percentage of material waste during construction.

(1) $C_{w,y} = M_y \times W_c$

where:

$C_{w,y}$ = amount of material waste discarded during construction in year y;

M_y = the amount of a given material consumed in the U.S. in year y; and,

W_c = the percentage of material discarded during new construction or the installation phase of renovation.

Table 1. Percent of Material Discarded During Construction

Material	Percent Discarded
Concrete	3%
Wood Products	5%
Drywall and Plasters	10%
Steel	0%
Brick and Clay Tile	4%
Asphalt Shingles	10%
Asphalt Concrete	0%

Source: DelPico (2004) and Thomas (1991)

Any material incorporated into the actual structure remains until removed during renovation or demolition, at which point it becomes demolition waste.[2] Since C&D debris generated from demolition in a given year was dependent on the lifespan of each construction material, Cochran and Townsend (2010) calculated a range of C&D debris generation from demolition based on the short, typical and long lifespan of the material and source of C&D debris shown in Table 2, resulting in three different values for C&D demolition debris for each year by material and source.

Table 2. Lifespan of Construction Materials by Source (years)

Material	Source	Lifespan		
		Short	Typical	Long
Concrete	Buildings	50	75	100
	Roads & Bridges	23	25	40
	Other Structures	20	30	50
Lumber	Buildings	50	75	100
Railroad Ties	Other Structures	20	35	45
Plywood and Veneers	Buildings	50	75	100
Wood Paneling	Buildings	20	25	30
Drywall and Plasters	Buildings	25	50	75
Steel	Buildings/ Roads & Bridges	50	75	100
Brick	Buildings	50	75	100
Clay Floor & Wall Tile	Buildings	15	20	25
Asphalt Shingles	Buildings	20	25	30

[2] Similarly as in Cochran and Townsend (2010), for a material such as asphalt shingles that reaches its assumed end of life before other materials associated with the same structure, EPA assumed that the material was removed from service through renovation, and it was accounted for in the demolition amount.

Table 2. Lifespan of Construction Materials by Source (years)

Material	Source	Lifespan		
		Short	Typical	Long
Asphalt Concrete	Buildings	20	25	30

Sources: Zapata and Gambatese (2005), Katz (2004), Park et al. (2003), Scheuer et al. (2003), Junnila and Horvath (2003), Chapman and Izzo (2002), Cross and Parsons (2002), Thormark (2002), Keoleian et al. (2001), Horvath and Hendrickson (1998), Bolt (1997), and Packard (1994), Bolin and Smith (2010) (2013). Additional corroboration with USGS (2010).

Table 3 shows the results for C&D debris generation of brick when using the Cochran and Townsend method for calculating demolition debris. While this method reflects the variability in demolition debris due to the uncertainty in material lifespan, each of the three demolition waste estimates were based on a single data point, i.e., historical consumption data for a single year. Furthermore, to provide a clearer depiction in the variance of the total amount using this method, the overall C&D debris generation was presented as a range. However, a single representative total waste value may be more useful to policymakers. To calculate a single representative total waste value for each material and source in a given year, only one demolition debris estimate must be chosen. However, it is not clear which of the three demolition debris estimates (short, typical, or long) would be the most representative of actual demolition debris generated in a given year.

Table 3 reveals that the demolition debris estimate for bricks calculated with the Cochran and Townsend method using the typical 75-year lifespan for bricks ranged from nearly 20 million short tons in 2000 to less than three million short tons in 2008. Because waste generation during construction remained fairly steady and contributed less than 10 percent of total C&D debris between 2000 and 2008, demolition debris estimates drove the observed changes. The rapid drop in demolition debris generation between 2004 and 2007 was due to falling consumption of bricks for construction as the Great Depression began in the late 1920s. A strong economy is indicative of high construction activity, and demolition activity to make space for new construction often precedes it. It seems unlikely that in 2007, at the height of the U.S. economy before the recession, demolition waste from bricks would be half of what it was in 2006 and a quarter of what it was in 2005 simply because of low consumption during the Great Depression 75 years ago. The same issues that caused highly variable C&D debris generation using a typical material lifespan can also affect demolition debris estimates using short or long lifespans.

Table 3. U.S. Annual C&D Brick Debris Generation Using Cochran and Townsend's (2010) Method to Calculate Demolition Debris Generation (tons)

Year	Brick Waste During Construction	Demolition Brick			Total C&D Brick Debris		
		Short Life	Typical Life	Long Life	Short Life	Typical Life	Long Life
2000	587,758	12,179,134	19,317,299	14,411,013	12,766,891	19,905,057	14,998,771
2001	568,881	12,756,344	19,163,376	16,258,085	13,325,224	19,732,257	16,826,966
2002	567,509	11,332,559	18,220,600	17,181,621	11,900,068	18,788,109	17,749,131
2003	568,572	11,294,078	16,989,218	17,123,900	11,862,650	17,557,790	17,692,472
2004	637,008	12,929,507	14,699,618	17,508,707	13,566,515	15,336,626	18,145,715
2005	661,298	15,199,867	11,755,846	19,932,990	15,861,165	12,417,145	20,594,288
2006	613,987	15,565,433	6,195,389	20,471,719	16,179,420	6,809,376	21,085,706
2007	523,995	12,814,065	2,693,647	19,971,470	13,338,059	3,217,642	20,495,465
2008	390,968	12,159,893	2,482,004	16,161,883	12,550,861	2,872,971	16,552,851

Table 3. U.S. Annual C&D Brick Debris Generation Using Cochran and Townsend's (2010) Method to Calculate Demolition Debris Generation (tons)

Year	Brick Waste During Construction	Demolition Brick			Total C&D Brick Debris		
		Short Life	Typical Life	Long Life	Short Life	Typical Life	Long Life
2009	276,945	14,122,408	2,693,647	20,413,998	14,399,352	2,970,592	20,690,943
2010	259,572	13,352,794	4,386,797	19,086,415	13,612,366	4,646,369	19,345,987
2011	237,394	12,852,545	7,349,809	17,701,110	13,089,939	7,587,203	17,938,504
2012	234,836	13,256,593	8,061,701	18,028,196	13,491,429	8,296,538	18,263,033
2013	183,865	14,257,090	6,791,839	17,162,381	14,440,956	6,975,705	17,346,246
2014	183,597	15,142,146	9,100,680	15,315,309	15,325,742	9,284,276	15,498,905

Instead of calculating demolition debris generation based on one service life at a time (short, typical, long), EPA calculated an average demolition debris generation for the full range of years within each material's expected lifespan. The demolition debris generation from brick in 2014 was used as an example. The expected lifespan of brick ranged from 50-100 years (Table 2). EPA calculated demolition debris resulting from consumption of bricks for each year in 1914-1964, and then averaged the results. Equation 2 below shows the calculation used to estimate demolition waste for a given year.

$$(2)\quad D_{w,y} = \frac{\sum_{i=(y-l)}^{(y-s)} (M_i - C_{w,i})}{(l-s)+1}$$

where:

y = the given year for which demolition waste generation is calculated;

l = the longest expected lifetime of the material (see Table Y);

s = the shortest expected lifetime of the material;

$D_{w,y}$ = the amount of demolition waste generated from material removed during renovation or demolition in year y;

M_i = the amount of a given material consumed in the U.S. in year i, where i ranges from year y-l to year y-s;

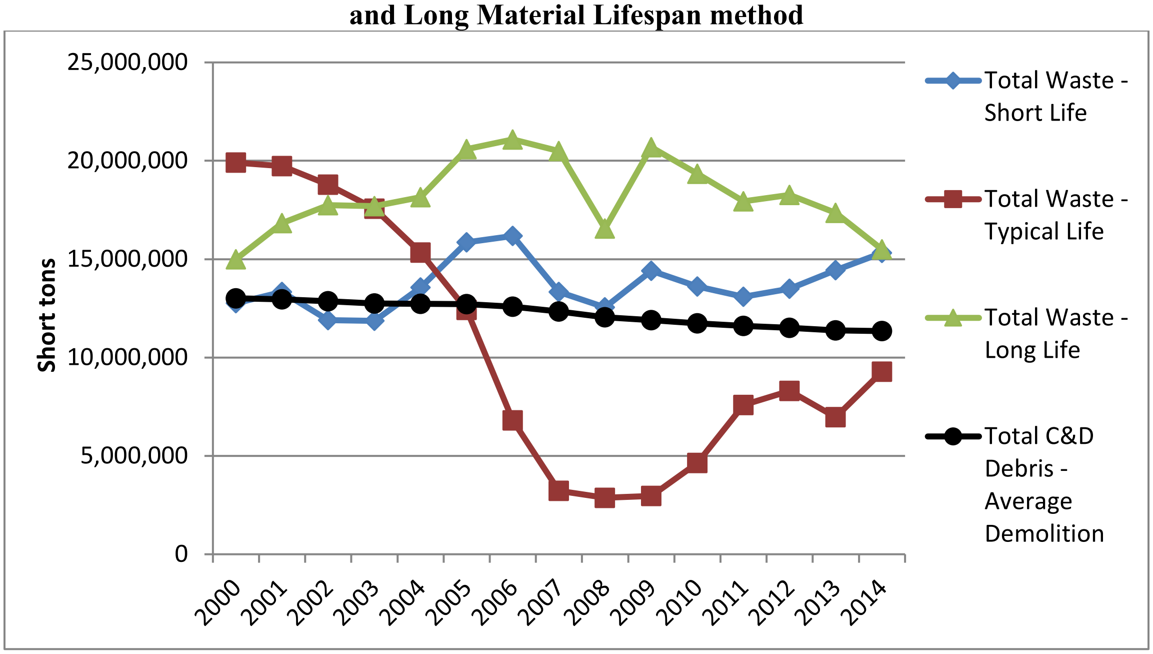
$C_{w,i}$ = the amount of material wasted during construction in year i, where i ranges from year y-l to year y-s.

Table 4 shows waste generated during construction, demolition, and total C&D debris from bricks for 2000-2014 using this averaging method. The total C&D debris estimates using EPA's method were much less susceptible to the influence of a single historical year's construction and consumption activity. Figure 2 shows total C&D brick debris generated between 2000 and 2014 using EPA's method to estimate demolition debris compared to the Cochran and Townsend method.

Table 4. U.S. Annual C&D Debris Generation from Bricks Using Average Demolition Debris Generation over the Range of Material's Useful Life (tons)

Year	Waste Brick During Construction	Demolition Brick	Total C&D Brick Debris
2000	587,758	12,423,599	13,011,357
2001	568,881	12,391,155	12,960,035
2002	567,509	12,294,576	12,862,085
2003	568,572	12,179,134	12,747,706
2004	637,008	12,096,891	12,733,898
2005	661,298	12,051,619	12,712,918
2006	613,987	11,965,981	12,579,968
2007	523,995	11,815,831	12,339,825
2008	390,968	11,662,663	12,053,630
2009	276,945	11,622,673	11,899,617
2010	259,572	11,484,218	11,743,790
2011	237,394	11,361,985	11,599,379
2012	234,836	11,274,838	11,509,674
2013	183,865	11,200,894	11,384,760
2014	183,597	11,161,282	11,344,879

Figure 2. Comparison of Total C&D Debris Generation for Bricks EPA's Average Demolition Method* and Cochran and Townsend's Short, Typical and Long Material Lifespan method



***Total C&D Debris – Average Demolition estimates shown in Table 4.**

2.2 Historical Consumption Data

The following seven sections describe the historical consumption data used for each construction material, and any assumptions necessary to determine the share of consumption associated with the construction of buildings, roads and other structures.

Concrete

In the methodology developed to estimate C&D debris generation in 2014, C&D concrete represents concrete made using either portland cement or a mix of portland cement and fly ash for cementitious material. The methodology used to estimate concrete consumption in the *Advancing Sustainable Materials Management: Facts and Figures 2013* report did not account for the use of fly ash. This year's addition of fly ash use improves the approximation of the overall amount of cementitious materials used in the manufacturing of concrete, which in turn, improves the accuracy of concrete consumption and generation estimates.

EPA started to derive historical concrete consumption based on cement consumption data published by the USGS for the years 1900 to 2014 (USGS, 2014a) (van Oss, 2015a and 2015b). The USGS also reports the amount of cement, including portland cement for 1975-2013 (USGS, 2005) (van Oss, 2015b). Since cement consumption statistics were not readily available for years prior to 1975, EPA assumed 96 percent of cement was portland cement, based on the data for 1975-2013. For 2014, EPA assumed the same percentage of portland cement as in 2013. In addition to portland cement consumption, EPA also converted fly ash consumption to concrete consumption. EPA used data on fly ash purchased for use in concrete and concrete products published by the American Coal Ash Association for the years 2000 to 2014 (ACAA, 2015).[3] EPA used these same sources to add fly ash consumption to portland cement consumption for 2012 and 2013 and re-estimate the total C&D debris generation from concrete for 2012 and 2013, resulting in increases in concrete C&D debris for both years.

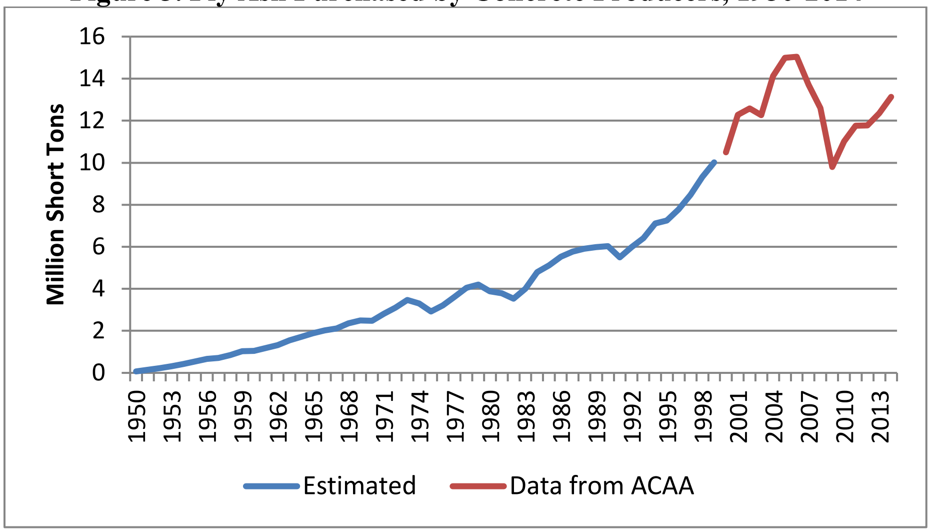
Although the possibility of substituting fly ash for portland cement in concrete has been known since the early 1900s, fly ash was not incorporated into concrete in large quantities until the 1950s (Thomas, 2007). Fly ash may replace portland cement at rates ranging from 15 to 40 percent by mass, depending on the composition of the fly ash and the type of construction in which the fly ash concrete will be used (EPA, 2014). In 2000, fly ash purchased by concrete producers made up 8.2 percent of total cementitious material input. A stepwise increase of 0.16 percent from zero percent in 1949 to eight percent in 1999 was used to estimate the amount of fly ash used by concrete producers from 1950 to 1999 (see Figure 3).

EPA converted portland cement and fly ash consumption into estimated concrete consumption using the density of cement and concrete and amount of cement and fly ash used per unit of concrete. Because fly ash is a supplementary cementitious material, it is substituted one to one for portland cement on a mass basis (van Oss, 2016). As cited by Cochran and Townsend (2010), the 2003 American Society for Testing Materials (ASTM) International standard reported an average density of 2,300 kg/m^3 for concrete, and the Portland Cement Association (PCA) gave an average density of 3,150 kg/m^3 for portland cement and a typical concrete

[3] U.S. cement and concrete producers purchase fly ash from coal-fired power plants to blend with cement. Most fly ash is purchased directly by concrete producers instead of cement producers. USGS historical cement consumption data only include data from cement producers (Thomas, 2007).Therefore, most of the fly ash consumed in concrete will not be captured using the USGS data on its own.

composition of 11 percent portland cement by volume. These values translated to 6.64 tons of concrete consumed per ton of portland cement.[4]

Figure 3. Fly Ash Purchased by Concrete Producers, 1950-2014



EPA used the method suggested by Cochran and Townsend (2010) to allocate consumption of concrete across the three sources of concrete C&D debris: buildings, roads and bridges and other structures. PCA estimated that in 2002, 47 percent of portland cement was used in buildings, 33 percent in roads and bridges, and 20 percent in other structures (Townsend and Cochran, 2010). Since this study assumes concrete consumption is directly related to cement consumption, the 2002 percentages for cement were used to calculate concrete consumption by buildings, roads and bridges and other structures in 2002. The following list describes the steps taken to estimate the division of concrete consumption among buildings, roads and bridges and other structures using the ratio from PCA and historical datasets from the U.S. Census Bureau on the annual value of construction put-in-place [5] grouped by type of structure (U.S. Census Bureau, 1975a, 1975b, 2003, 2016a, and 2016b). EPA used differences in construction spending between 2002 and a given year in each of the three source categories to adjust the 2002 percentages from PCA to reflect changes in the distribution of concrete consumption between buildings, roads and bridges and other structures over time.

1. Converted all construction put-in-place values into 1996 constant dollars:
    a. 1964-2002 values (U.S. Census Bureau, 2003a): No conversion necessary.
    b. 1915-1963 values (U.S. Census Bureau, 1975a): Converted values presented in 1957-1979 constant dollars by multiplying each value by a factor of 6.39, which was the relative value of a constant 1996 dollar to constant 1957-1959 dollar based on index tables. This value was computed by 1) calculating the ratio of the 1970 index value and 1957-1959 index value using data from series N1 and N30 (U.S. Census Bureau, 1975a); 2) calculating the ratio of the 1996

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[4] Although cement and concrete density values do not consider the addition of fly ash, in the absence of a more relevant factor, EPA used the same 6.64 portland cement-to-concrete ratio to convert the fly ash consumption to concrete consumption.

[5] *Value of construction put-in-place* represents the total dollar value of construction work done in the U.S.

index value to the 1970 index value in the 1964-2002 historical value of construction put-in-place (U.S. Census Bureau, 2003a and 2003b); and 3) multiplying these two ratios together.

c. For 2003-2014 values (U.S. Census Bureau, 2008 and 2015a): Converted values presented in current dollars using the annual price indexes of new single-family homes (U.S. Census Bureau, 2016c). The index for each year was calculated by multiplying the current dollar for a given year by the 1996 index value and dividing by the index value of the given year.

2. Calculated construction put-in-place for buildings, roads, and other structures by summation of subcategory values (in constant 1996 dollars).

    a. For 1915-2002, the buildings category included residential and non-residential buildings from private and public construction as well as non-residential farm construction; roads includes publicly constructed highways, roads, and streets; and other structures includes all privately constructed public utilities and all other private structures as well as public construction of military facilities, sewer and water systems, conservation and development, public service enterprises and all other public structures.

    b. For 2003-2014, the buildings category included residential and non-residential lodging, office, commercial, health care, educational, religious, public safety and amusement and recreation categories; roads includes the highways and streets category; and other structures includes the communication, power, transportation, sewer and waste disposal, water supply, conservation and development and manufacturing categories.

3. Calculated the ratio of spending to tons of concrete (constant 1996 dollars/ ton) consumed for buildings, roads and bridges and other structures in 2002.

    a. Multiplied total concrete consumption in 2002 by PCA's estimated distribution of cement among the three sources in 2002 (47 percent for buildings, 33 percent for roads and bridges and 20 percent for other).

    b. Divided 2002 construction put-in-place values for buildings, roads and bridges and other structures (in constant 1996 dollars) by tons of concrete consumed by each of the three categories.

4. Calculated the percent of concrete use by source for each year using the spending per ton of concrete ratios developed in Step 3.

    a. Divided spending (in constant 1996 dollars) on buildings, roads and bridges, other structures and total construction spending for each year by the corresponding 2002 spending per ton of concrete ratio for each source.

    b. Divided the tons of concrete for each source estimated in Step 4a using 2002 spending ratios by the total tons of concrete for that year derived from construction spending to calculate percent distribution of concrete consumption across buildings, roads and bridges and other structures for the years 1915-2014.

    c. Estimated 1900-1914 concrete consumption distribution for the three sources based on the average distribution for 1915-2014.

5. Calculated the tons of concrete consumed for buildings, roads and bridges and other structures in a given year by multiplying the total tons of concrete consumed in construction (based on USGS cement

consumption data) by the percent distribution of concrete use associated with each source (Step 4) for a given year.

Note that revisions were made in the distribution of concrete consumption in the three C&D debris source categories for 2003 through 2013 due to changes in Value of Construction Put-in-Place data published by the U.S. Census Bureau for those years.

The revisions made to the distribution of concrete consumption across the three source categories; updates to the 2012 and 2013 portland cement consumption data published by USGS (2015); and the methodology developed this year to include fly ash in the calculation of concrete consumption, resulted in revised concrete generation estimates from previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013.* The total concrete generation estimates in the previously published report of 348.449 million tons in 2012 and 352.871 million tons in 2013 were revised to 364.394 million tons in 2012 and 369.542 million tons in 2013.

Wood Products

The USGS published consumption data from the USFS for lumber, wood paneling, and plywood and veneer products available for 1900 to 2011 (USGS, 2014b). The USFS provided additional data for 2012 and 2013 (Howard and Jones, 2016) as well as preliminary data for 2014 (Howard, 2016). EPA assumed that all wood panels as well as plywood and veneer are used in building applications. For lumber, EPA relied on the study published by the USFS reporting approximately 78 percent of lumber use for construction (Howard, 2007). [6] EPA split that amount between buildings and railroad ties and calculated C&D lumber generation per those two sources. Namely, lumber consumed for construction of buildings was calculated by subtracting the amount of wood used for railroad ties from total lumber used in construction.

Consumption of lumber for railroad ties was based on data for annual rail tie installations from the Rail Tie Association (RTA 2014 and 2015) (Gauntt, 2012, 2013, and 2014) and conversions associated with the use of wood in rail ties. Data were available for the number of ties installed for Class 1 railroads from 1921 through 2014 and for short line and regional railroads from 2011 through 2014. EPA assumed an annual installation rate of six million ties for the years 1900 through 1920 based on the average number of new ties installed from 1921 to 1930. Data for switch and bridge ties included annual board footage for 1995 through 2014.

To calculate the weight of wood consumed annually from the number of ties installed and the board footage of switch and bridge ties, EPA used standard conversion factors. According to the Rail Tie Association, a typical tie is seven inches tall by nine inches wide by 8.5 feet long, which is equivalent to 3.72 cubic feet per tie. Reported board footage for switch and bridge ties was converted to cubic feet by dividing by 12. EPA used a factor of 20.2 short tons/1000 cubic feet of ties based on USFS volume-to-weight conversion factors for hardwood lumber from USFS (1990).

Construction waste associated with the installation of ties was estimated to be five percent of annual consumption; the same rate that was used to estimate the amount of other wood products discarded during construction. To

[6] The remaining 22 percent of lumber is used in non-construction applications including transport packaging such as pallets and manufacturing wooden consumer goods such as furniture (Howard, 2007).

estimate demolition waste, railroad ties were assumed to have a lifespan ranging from 20 to 45 years with an average useful life of 35 years (Bolin and Smith, 2010 and 2013).

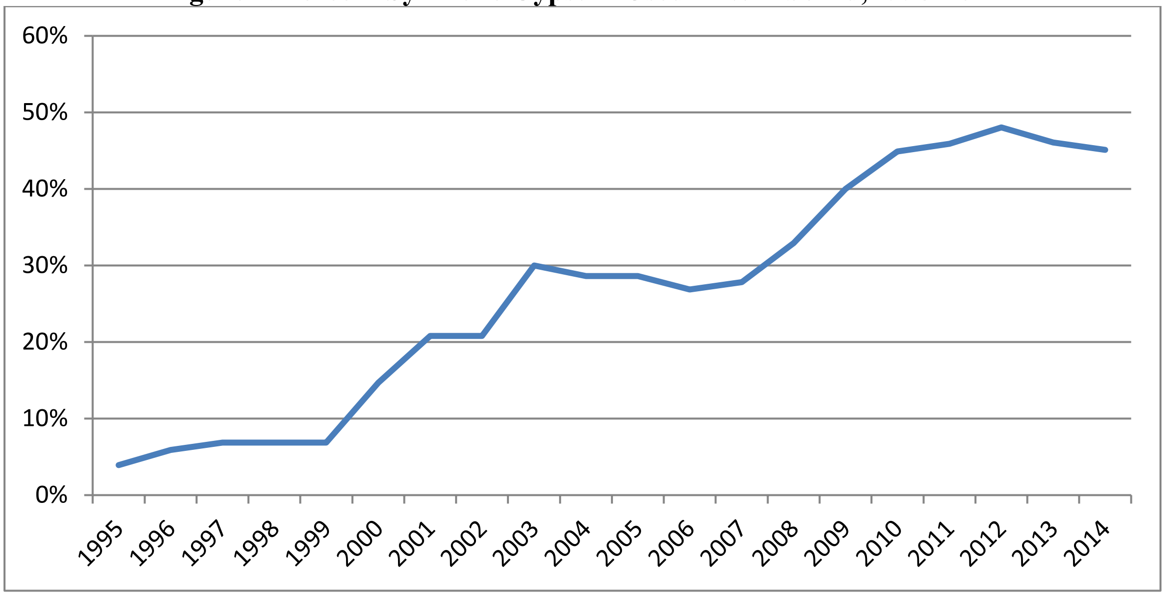
The updated consumption data from USFS for 2012 and 2013, as well as the new methodology developed to estimate C&D debris generation for railroad ties, resulted in the revision of generation estimates previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013* for lumber, wood paneling and plywood and veneer products. The total wood products generation estimates in the previously published report of 39.968 million tons in 2012 and 40.217 million tons in 2013 were revised to 37.664 million tons in 2012 and 38.172 million tons in 2013.

Gypsum Drywall and Plasters

EPA used USGS historical consumption data for gypsum for 1900 through 2014 (USGS, 2014c) (Crangle, 2015a and 2015b). USGS also published end-use statistics for gypsum, available for 1975-2013, which documented annual consumption of drywall (listed as prefabricated products) and plasters made from calcined gypsum (USGS, 2005b) (Crangle, 2015b). EPA used these data to calculate the percent of gypsum consumed by drywall and plasters for the years 1975-2013. To calculate annual drywall and plaster consumption before 1975, EPA multiplied total apparent gypsum consumed each year in 1900-1974 by 75 percent, the average percent of gypsum used in drywall and plasters during 1975-2012. EPA assumed the same percent of gypsum used in drywall and plasters for 2014 as calculated for 2013.

Over the last two decades, an increasing amount of gypsum used in construction products has been synthetically produced as a byproduct of emissions control devices at coal-fired power plants. As shown in Figure 4, the Gypsum Association tracks and publishes the amount of synthetic gypsum, also known as flue gas desulphurization (FGD) gypsum, as a percent of total gypsum used in wallboard (Gypsum Association, 2015). As shown in Figure 4, the percent of synthetic gypsum used in wallboard was less than five percent in 1995. The short lifespan for drywall and plaster products was estimated to be 25 years (Table 2), which results in 1989 being the most recent consumption data point considered for drywall demolition debris. In 1989, the percent of synthetic gypsum used would have been less than the percent used in 1995. It is, therefore, unlikely that drywall and plaster products made with FGD gypsum represented more than de minimis amounts in the demolition debris generated from 2012- 2014. However, drywall and plaster products made with FGD gypsum did contribute to the construction debris for gypsum drywall and plaster from 2012 - 2014.

Figure 4. Percent Synthetic Gypsum Used in Wallboard, 1995-2014



Updated gypsum consumption data published by USGS for years 2012 and 2013 resulted in revisions of drywall and plaster generation estimates previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013*. The total drywall and plaster generation estimates in the previously published report of 12.614 million tons in 2012 and 13.059 million tons in 2013 were revised to 12.517 million tons in 2012 and 12.832 million tons in 2013.

Steel

The *Statistical History of the United States: From Colonial Times to the Present* from the U.S. Census Bureau (1975c) provided the amount of structural iron and steel shapes produced for 1900-1970 and USGS published steel consumption data for 1979 through 2013 by end-use, including construction (USGS, 2005c) (Fenton, 2015b). Steel consumption for construction for 1971-1978 was estimated by interpolation based on data for 1970 and 1979. EPA estimated 2014 steel consumption for construction using the total apparent steel consumption reported by USGS (Fenton, 2015a) and the assumption that the percent of steel consumed by construction activities in 2014 remained the same as in 2013 (Fenton, 2015b).

Updated 2013 steel consumption data from USGS resulted in revised steel C&D debris generation estimates previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013* report. Note that consumption of steel for construction includes total use in buildings and roads and bridges; data were not available to allocate steel use between buildings and roads and bridges. The total steel generation estimates in the previously published report of 4.230 million tons in 2012; and 4.282 million tons in 2013; remained virtually unchanged at 4.229 million tons in 2012; and 4.282 million tons in 2013.

Bricks and Clay Floor and Wall Tile

The U.S. Census Bureau's *Statistical History* (1975d) reported the number of bricks consumed for building construction for the years 1900-1969. EPA used the conversion factor of 499 bricks per short ton, converted from 550 bricks per metric ton as cited in Cochran and Townsend (2010). For 1970-2013, USGS published clay end-use data, including bricks, for common clay and shale (USGS, 2005d) (Virta, 1975 and 2015c) and kaolin clay (Virta, 2015d) for 1975-2013. For clay tile, EPA used USGS end-use data for common clay and shale (USGS, 2005d) (Virta, 1975 and 2015c), ball clay (USGS, 2005e) (Virta, 1975 and 2015b) and kaolin clay (Virta, 2015d) available for 1975-2013. For 2014, the USGS Mineral Commodity Summary provides an estimate of brick produced from common clay and shale and tile produced from ball clay (Virta, 2015a); consumption of bricks and tile from kaolin clay and tile from miscellaneous clay and shale were assumed the same in 2014 as reported in 2013.

Changes in brick and clay tile consumption data published by USGS resulted in revisions in the 2012 and 2013 generation estimates for clay tile and 2013 estimates for brick that were previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013*. The total brick and clay tile generation estimates in the previously published report of 12.180 million tons in 2012 and 12.110 million tons in 2013 were revised to 12.179 million tons in 2012 and 12.057 million tons in 2013.

Asphalt Shingles

Since historical data on asphalt shingle consumption were not readily available, EPA first estimated the amount of asphalt shingles consumed in a given year and then used an indicator to estimate changes in asphalt shingle consumption over time. While this method is based on Cochran and Townsend (2010), instead of using asphalt production as the indicator of changes in asphalt shingle consumption, EPA used the sales of roofing granules published by USGS. USGS end-use statistics for 1980-2012 included roofing granules made from construction sand and gravel (USGS, 2005f) (Bolen, 2014), crushed stone (Tepordei, 2006) (Willett, 2014) and silica (USGS, 2005g) (Dolley, 2015b). USGS end-use statistics for roofing granules consumed in 2013 were available for silica (Dolley, 2015b), but these data were not available for sand and gravel and crushed stone. The quantity of roofing granules from silica in 1980-2013 were used as reported by USGS. However, USGS reported large portions of sand and gravel and crushed stone as "unspecified uses" and only published data every other year between 1980 and 1994. To account for roofing granules included in unspecified uses for these two categories of aggregates, EPA calculated the percent roofing granules of all specified end uses for each year, and multiplied by total apparent consumption for each aggregate. For odd numbered years between 1980 and 1994 where USGS did not calculate roofing granules consumed, EPA estimated consumption by averaging the consumption from the previous and following years. In order to estimate roofing granules from sand and gravel and crushed stone in 2013 and 2014, for each aggregate, the ratio of roofing granules to total apparent consumption in 2012 was multiplied by the total apparent consumption in 2013 and 2014 (Bennett, 2015) (Willet, 2015). Roofing granules from silica in 2014 were calculated by multiplying total apparent consumption of silica in 2014 by the 2013 ratio of total apparent silica consumption to roofing granules (Dolley, 2015a and 2015b).

In 2006, the Asphalt Roofing Manufacturers Association (ARMA et al., 2011) reported sales of nearly 149,830,000 squares[7] of roof coverage. Table 1-1 in *Roofing the Right Way* (Bolt, 1997) presented a range of 210-250 pounds per square of roofing coverage. Using the midpoint of 230 pounds per square, EPA converted 2006 shingle sales in squares to tons of shingles sold in 2006. The final step entailed multiplying the weight of shingles sold in 2006 by the ratio of roofing granules consumed in a given year to roofing granules consumed in 2006.

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[7] One "square" refers to the amount of shingles required to cover 100 square feet of a roof.

Updates in the USGS data around the total apparent consumption for sand and gravel in 2012 and for crushed stone in 2012 and 2013 resulted in revisions in the 2012 and 2013 generation estimates for asphalt shingles previously published in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013*. The total asphalt shingles generation estimates in the previously published report of 12.807 million tons in 2012 and 12.603 million tons in 2013 were revised to 12.806 million tons in 2012 and 12.400 million tons in 2013.

Asphalt Concrete

Unlike Cochran and Townsend (2010) who used materials flow analysis and USGS end-use statistics on consumption of aggregates used in asphaltic and bituminous aggregates to estimate the generation of asphalt concrete, EPA used an estimated asphalt concrete recovery rate and data on RAP consumption published by NAPA and FHWA. EPA chose this method because RAP data are directly related to total asphalt concrete waste generation and no assumptions about the lifespan of the asphalt concrete were required.

NAPA's 2015 report (Hansen and Copeland, 2015) provides annual estimates of the tons of RAP from 2009 to 2014 based on their survey on recycled materials and warm-mix asphalt usage, data from state asphalt pavement associations, and each state's highway apportionment. RAP has a high value and NAPA states that 99 percent of asphalt concrete removed from service each year is reclaimed for reuse (Hansen and Copeland, 2015). Previously, in the *Advancing Sustainable Materials Management: Facts and Figures 2013* report, EPA had used a recycling factor of 80 percent. However, the 80 percent recycling rate was based on FHWA documentation from 1993 and is not considered representative of current asphalt pavement reclamation rates. Thus, to calculate total asphalt concrete waste generated, EPA divided the amount of RAP accepted by asphalt producers each year by 0.99 (Hansen and Copeland, 2014). The 2012 and 2013 asphalt concrete estimates published in *Advancing Sustainable Materials Management: Facts and Figures 2013* report have been revised to reflect the 99 percent reclamation rate. The total asphalt concrete generation estimates in the previously published report of 89.125 million tons in 2012 and 95.125 million tons in 2013 were revised to 72.020 million tons in 2012 and 76.868 million tons in 2013.

This method does not capture asphalt concrete sent to mixed C&D debris or aggregate processing facilities and also may not capture asphalt concrete waste generated from smaller scale operations, such as parking lot or driveway resurfacing or tear out that are sent straight to the landfill and therefore not accounted for by NAPA's survey of asphalt mix producers.

2.3 C&D Debris Generation Results

This section presents results for 2012, 2013 and 2014 C&D debris generation estimates. Table 5 displays the amount of C&D debris generated from buildings, roads and bridges and other structures for each material. The "other structures" category included C&D debris from wooden railroad ties and concrete used in communication, power, transportation, sewer and waste disposal, water supply, conservation and development and manufacturing infrastructure. Although results did not vary greatly between 2012, 2013 and 2014, C&D debris generation rose slightly each consecutive year for all material types except railroad ties, bricks and clay and a small dip in asphalt shingle debris in 2013.

Methodological improvements for calculating historical concrete consumption by including fly ash used in concrete production resulted in an increase in the concrete C&D debris generation estimates for 2012 and 2013 previously reported in EPA's *Advancing Sustainable Materials Management: Facts and Figures 2013* by 16.7 and 17.4 million short tons, respectively. Total generation results for 2012 and 2013 were lower than previously published in large part due to the adjustment in methodology for calculating asphalt concrete generation.

Table 5. C&D Debris Generation by Source (thousand tons)

	Buildings			Roads and Bridges			Other		
	2012	2013	2014	2012	2013	2014	2012	2013	2014
Concrete	78,236	81,054	84,763	156,259	157,068	157,384	129,898	131,420	133,150
Wood Products[1]	36,252	36,771	37,304				1,412	1,400	1,376
Drywall & Plasters	12,517	12,832	13,590						
Steel[2]	4,229	4,282	4,349						
Brick & Clay Tile	12,179	12,057	12,041						
Asphalt Shingles	12,806	12,400	13,542						
Asphalt Concrete				72,020	76,868	76,565			
Total	*156,222*	*159,397*	*165,591*	*228,279*	*233,936*	*233,949*	*131,310*	*132,821*	*134,527*

1 Wood consumption in buildings also includes some lumber consumed for the construction of other structures. Data were not available to allocate lumber consumption for non-residential and unspecified uses between buildings and other structures except for railroad ties. Since non-residential buildings such as barns, warehouses, and small commercial buildings are assumed to consume a greater amount of lumber than other structures, the amount of lumber for construction remaining after the amount for railroad ties is split out is included in the buildings source category.

2 Steel consumption in buildings also includes steel consumed for the construction of roads and bridges. Data were not available to allocate steel consumption across different sources, but buildings are assumed to consume the largest portion of steel for construction.

Figure 5 illustrates waste generation for 2014 and highlights that roads and bridges contributed significantly more to C&D debris generation in 2014 than buildings and other structures, and concrete made up the largest share of C&D debris generation for all three categories. In 2014, railroad ties made up only about 3.5 percent of C&D debris from all wood products and only one percent of C&D debris from other structures.

Table 6 presents C&D debris generated by activity (i.e. construction and demolition) and total C&D debris for each material. Total C&D debris generation was about 516 million tons in 2012, 526 million tons in 2013 and 534 million tons in 2014. As for C&D debris reported by source (Table 5), results categorized by activity were similar across each year. Concrete consumption created much more waste during construction than any other material. However, Figure 6 shows that waste during construction for drywall and plasters contributed a much greater percentage of the overall C&D debris for drywall and plasters than was the case for concrete. As noted in the methodology section for gypsum drywall and plasters, products made with FGD gypsum are unlikely to have been on the market long enough to have had much of an impact on demolition debris during 2012 through 2014. However, FGD gypsum found in drywall and plaster products that were generated during construction contributed 11 percent of the 10,271 tons of drywall and plaster C&D debris generated in 2014. Demolition played the largest role in determining C&D debris generation, as demolition debris comprised over 90 percent of total C&D debris generation for all materials except drywall and plasters.

Figure 5. C&D Debris Generated in 2014 by Material and Source

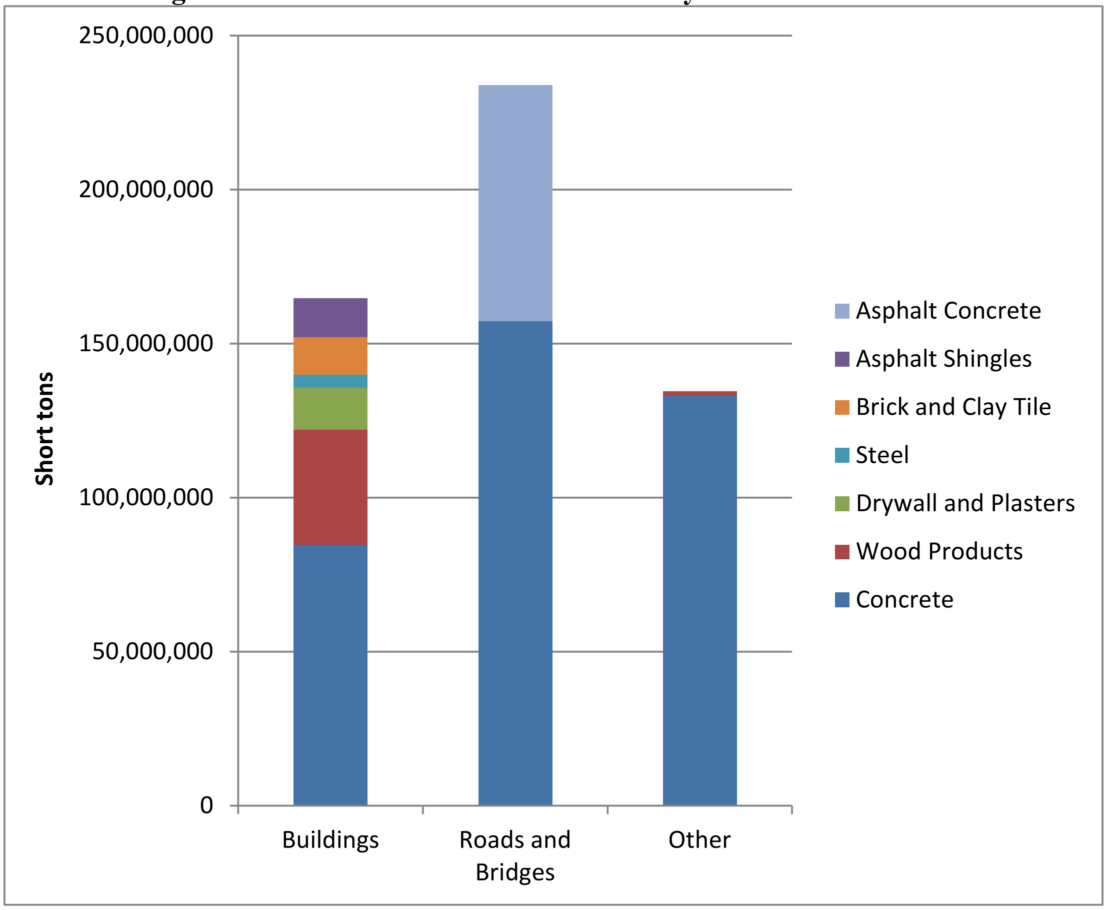
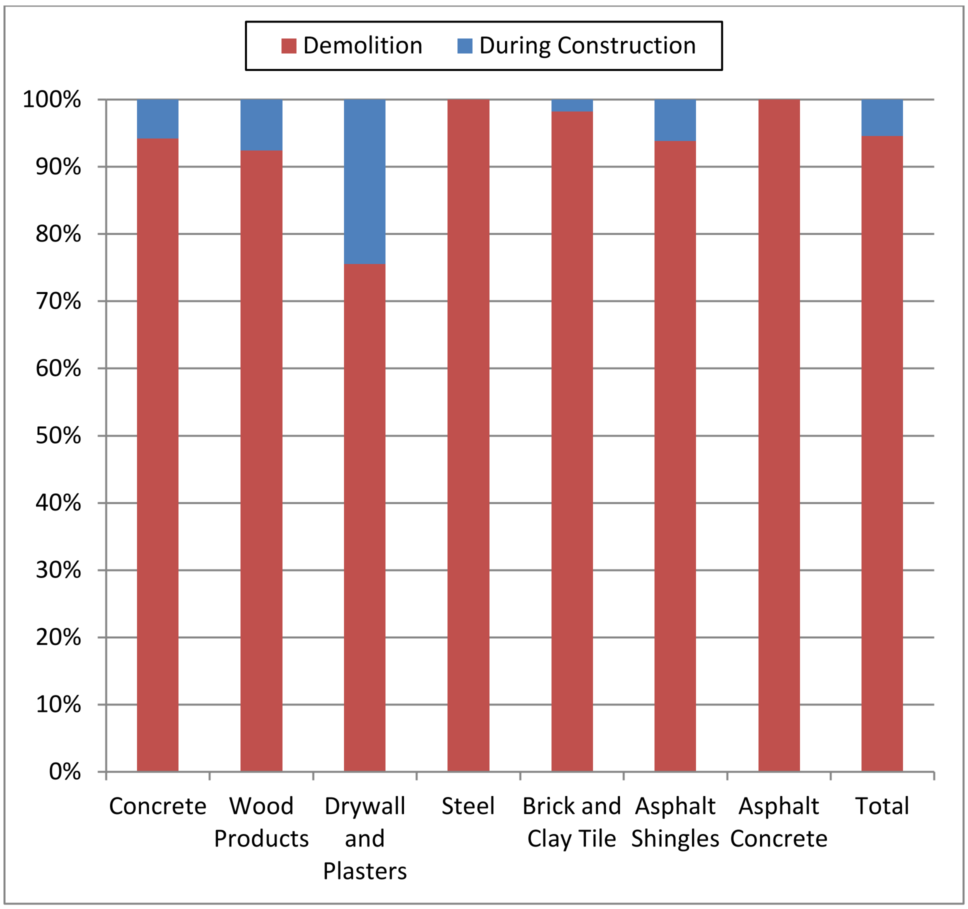


Table 6. C&D Debris Generation by Material and Activity (thousand tons)

	Waste During Construction			Demolition Debris			Total C&D Debris		
	2012	2013	2014	2012	2013	2014	2012	2013	2014
Concrete	19,017	19,939	21,664	345,376	349,603	353,633	364,394	369,542	375,297
Wood Products	2,506	2,691	2,922	35,158	35,481	35,757	37,664	38,172	38,680

Drywall & Plasters	2,881	2,896	3,319	9,636	9,935	10,271	12,517	12,832	13,590
Steel	0	0	0	4,229	4,282	4,349	4,229	4,282	4,349
Brick & Clay Tile	265	212	211	11,914	11,844	11,829	12,179	12,057	12,041
Asphalt Shingles	1,023	832	828	11,783	11,567	12,713	12,806	12,400	13,542
Asphalt Concrete	0	0	0	72,020	76,868	76,565	72,020	76,868	76,565
Total	*25,693*	*26,571*	*28,947*	*490,118*	*499,583*	*505,121*	*515,812*	*526,155*	*534,068*

Figure 6. Contribution of Construction and Demolition Phases to Total 2014 C&D Debris Generation



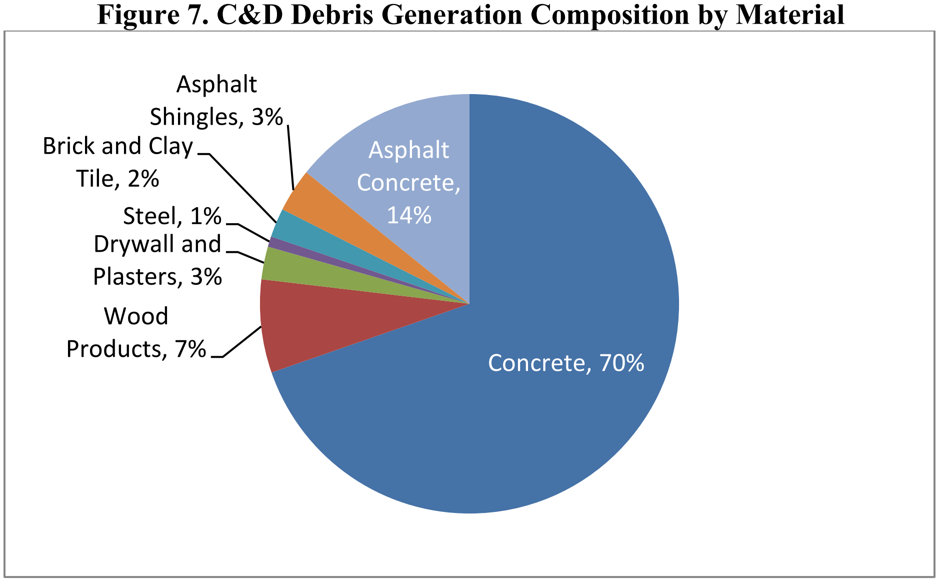
3.0 C&D Debris Generation Composition

The 2014 C&D debris generation composition estimates presented in detail in Table 7 are also depicted in Figure 7. Concrete was the largest portion (70 percent), followed by asphalt concrete (14 percent). These materials are used in both building and road and bridge sectors. Wood products made up seven percent and the other products accounted for eight percent combined.

Table 7. C&D Debris Generation Composition by Material and Source

	Total Generation in 2014 (thousand tons)	% of Total Generation in 2014
Concrete from Buildings	84,763	15.9%
Concrete from Roads and Bridges	157,384	29.5%
Concrete from Other Structures	133,150	24.9%
Lumber from Buildings	26,572	5.0%
Railroad Ties	1,376	0.3%
Wood Panel Products	8,663	1.6%
Plywood and Veneer	2,067	0.4%
Drywall and Plasters	13,590	2.5%
Steel	4,349	0.8%
Brick	11,344	2.1%
Clay Tile	696	0.1%
Asphalt Shingles	13,542	2.5%
Asphalt Concrete	76,565	14.3%
Total	*534,068*	*100%*

Figure 7. C&D Debris Generation Composition by Material



4.0 *Conclusions*

The C&D debris generation methodology developed and presented in this memorandum was structured to allow the continuation of the analysis in future years. All historical consumption and distribution data are in place for concrete, steel, wood products, gypsum wallboard and plaster, brick, clay tile, and asphalt shingles. The asphalt concrete generation estimate, based on industry data, can be easily updated. It is anticipated that the asphalt industry source will continue to gather and publish the data required for this methodology. Future work in estimating disposal of asphalt concrete may provide a better estimate of generation through addition of annual quantities of reclaimed and disposed asphalt concrete. Two data points that need updating in future estimates are the Asphalt Roofing Manufacturers Association's asphalt shingle sales data and the Portland Cement Association's estimation of cement consumption by end use. These data points are from 2006 and 2002, respectively. More recent data would improve the methodology assumptions for asphalt shingles and cement end-use markets. Further research is also needed to determine the distribution of steel C&D debris generation across the buildings, roads and bridges and other structures categories.

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