Construction and Demolition Debris Management in the United States, 2015
U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery
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1.0 Executive Summary

Construction and demolition (C&D) debris includes a variety of materials that are generated from construction, renovation, and demolition of buildings, roads and bridges, and other structures. The U.S. Environmental Protection Agency (EPA) publishes annual estimates of the amounts of C&D debris generated in the U.S. in its *Advancing Sustainable Materials Management: Facts and Figures* publications (the "SMM: Facts and Figures").

In 2019, EPA also published a methodology to quantify the end-of-life (EOL) management of the materials generated in C&D debris in the U.S. (the "CDDPath"). The Agency applied the CDDPath to estimate the 2014 mass quantity of C&D debris managed by landfilling or processing for use. The CDDPath, and the 2014 data, are explained and presented in a Waste Management journal article, *CDDPath: A method for quantifying the loss and recovery of construction and demolition debris in the United States* (Townsend et al. 2019).

This memo builds on the journal article by using the CDDPath methodology and updating the data sources to produce new estimates for the 2015 mass quantities of C&D debris material directed to landfills or intended for next use.[1] The objectives for the memo are to summarize the relevant methodology steps from the CDDPath and to present the 2015 estimates of the mass quantities of materials in the C&D debris stream directed to landfills or intended for next use.

The data sources upon which the 2015 estimates are based, span a variety of studies of the C&D debris stream's generation, composition, and management. They include the EPA's *Construction and Demolition Debris Generation in the United States, 2015* (the "C&D Debris Generation, 2015") research memo (EPA 2018b); the National Asphalt Pavement Association's (NAPA's) Asphalt Pavement Industry Survey of asphalt-mix producers (the "2015 NAPA Survey") (NAPA 2017); state and local studies with mass quantities of C&D debris landfilled or processed for next use in state-permitted solid waste management facilities; state and local waste composition studies; and, the Construction and Demolition Recycling Association (CDRA) member survey about material quantities processed for next use (the "CDRA Survey") (CDRA 2014) (Townsend et al. 2018).

In this memo, "next use" designates an intended next-use market for a C&D material, which depending on the material may include fuel, manufactured products, aggregate, compost and mulch, or soil amendment. The "manufactured products" next use encompasses estimates of C&D debris material quantities processed (e.g.,

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[1] This memo replaces the terms "landfilling" and "processing for use" from the journal article, with "landfills" and "next use," and transfers the focus from EOL management "pathways" to "end destinations." Therefore, a pathway from the journal article means a landfill or next-use market. Accordingly, this memo will also replace the "remanufacture" pathway from the journal article with the "manufactured products" next-use market.

ground, crushed, or extracted and melted) for incorporation in the manufacture of new materials and products. Depending on the C&D material, the "manufactured products" next use may include estimates of:

- C&D wood processed for use as feedstock in the manufacture of derivative products, such as engineered wood products;
- C&D shingles processed for use as feedstock in the production of asphalt mixtures;
- C&D drywall processed for use as feedstock in the manufacture of new drywall or portland cement;
- C&D metals processed for use in the production of metal precursor products, such as billets and ingots;
- C&D concrete processed for use as aggregate in the manufacture of concrete and the production of asphalt mixtures;
- C&D asphalt processed for use in the production of asphalt mixtures.

Underlying Framework and Data Sources

EPA's C&D Debris Generation, 2015, memo provides information about the 2015 generation amounts of C&D wood, drywall, steel, concrete, brick and clay tile, and asphalt shingles. The 2015 NAPA Survey defines the 2015 generation and EOL management of source-separated reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS). State data provide information about C&D debris amounts directed to landfills or processed for next use in state-permitted solid waste management facilities. Finally, from a sample of CDRA-member companies, the CDRA Survey provides information about quantities of specific materials processed for next use, and quantities processed for specific next uses for each material. Collectively, these data sources provide C&D debris generation estimates and help divide generation estimates into sum quantities sent to landfills versus next use, as well as across specific next uses for each material. These data sources are further noted and explained in the appendix to this memo.

The CDDPath methodology can be simplified into a three-stage calculation process. In the first stage, the total generated C&D debris is grouped into three main components: source-separated RAP and RAS; mixed C&D debris materials; and source-separated bulk aggregate. These three components are managed in three types of facilities: asphalt plants, state-permitted solid waste management facilities, and bulk aggregate processing facilities (CDRA 2014). Grouping C&D debris into the three components allows measured data about C&D debris EOL management from all types of facilities to be used, where available.

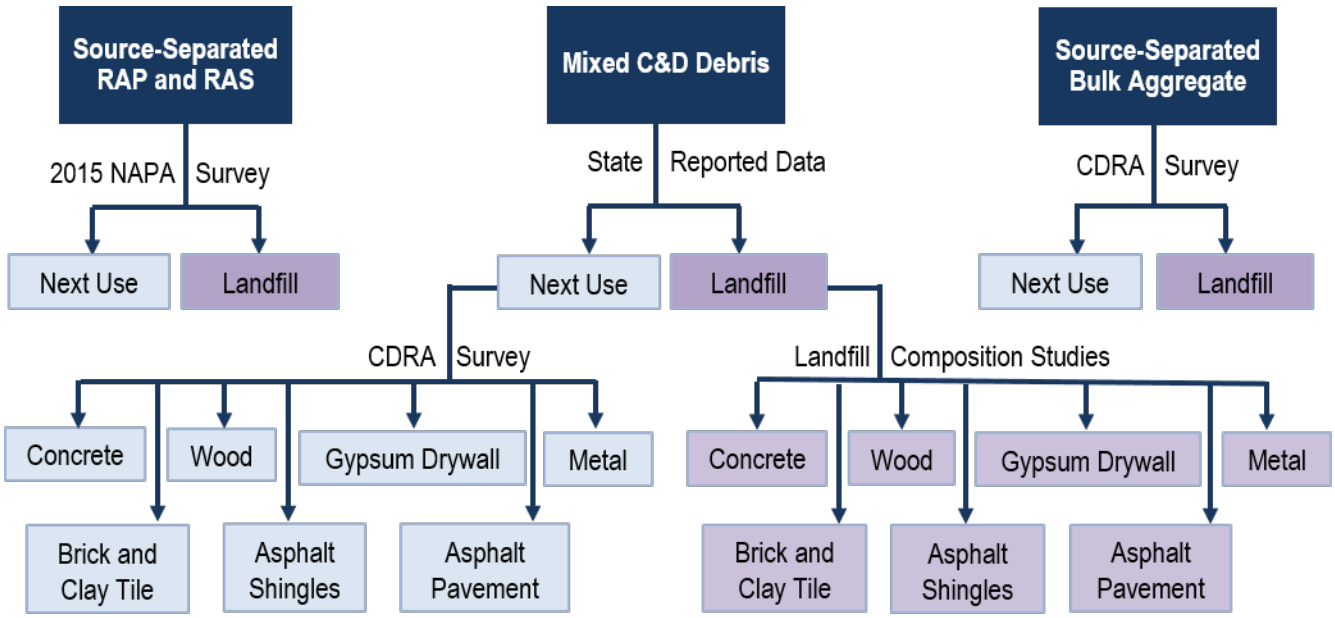
In the second stage, the total sum C&D debris generation quantity for each of the three components is divided up into the mass quantity of C&D debris materials intended for next use and the mass quantity directed to landfills. These mass quantities are developed by using ratios of next-use (material recovery) and landfilling amounts in the measured data from appropriate types of facilities.

Due to being composed of a variety of materials, the mixed C&D debris stream is unique relative to source-separated RAP, RAS, and bulk aggregate components. Unlike for the other two components, estimates of next-use and landfill quantities for the mixed C&D debris stream must be disaggregated to individual materials. This disaggregation is achieved by applying fractions (percentage values) attributed to each material in the stream from either the CDRA Survey (for next use) or state and local landfill studies (for landfills). This disaggregation is part of the second stage calculations for the mixed C&D debris only.

Figure ES-1 illustrates the first two stages of the CDDPath framework and highlights the data sources used at each stage. It shows the grouping of C&D materials into three main C&D debris components, source-separated

RAP and RAS, mixed C&D debris, and source-separated bulk aggregate. It also shows the second stage, where the quantity in each component is divided into estimates of amounts intended for next use or directed to landfills. Moreover, it shows the sum quantities of the mixed C&D debris intended for next-use or directed to landfills being disaggregated to individual materials.

Figure ES-1. Grouping C&D Materials into Components and Data Sources Used



The third stage begins once mass quantities intended for next use are estimated for all C&D materials in each of the three main C&D debris components. Each material's next-use quantity is apportioned across specific next uses that are characteristic for the material by applying percentages attributed to each next use in the CDRA Survey and/or the 2015 NAPA Survey.

Methodology

The previous section outlines the underlying framework for the CDDPath methodology. The actual methodology is applied over nine sequential steps. The focus is first placed on one component and then the next, until EOL destinations for all three components have been quantified.

- The process starts with the three main components being defined at Step 1. The total C&D debris amount is comprised of the amounts in these three components.
- Step 2 is focused on the first main component, **the source-separated RAP and RAS**, which are at EOL managed by the asphalt pavement industry. In Step 2, quantities of source-separated RAP and RAS sent to landfills or intended for next use along with each specific next-use market are estimated.
- Estimation of **the mixed C&D debris** streams (next-use and landfill), stretches from Step 3 to Step 7. Over these steps, preliminary next-use and landfill estimates are first developed for a portion of materials. Next-use and landfill estimates are finalized for these materials, and final values are extrapolated onto the remaining materials.

- Step 8 is focused on the third main component, **the source-separated bulk aggregate**. In Step 8, quantities of source-separated bulk aggregate intended for next use or sent to landfills are estimated.
- Finally, in Step 9, quantities of C&D materials in each next use are determined. In other words, the estimated next-use quantity for each C&D material is apportioned across specific next uses that are characteristic for the material.

Summary of Results

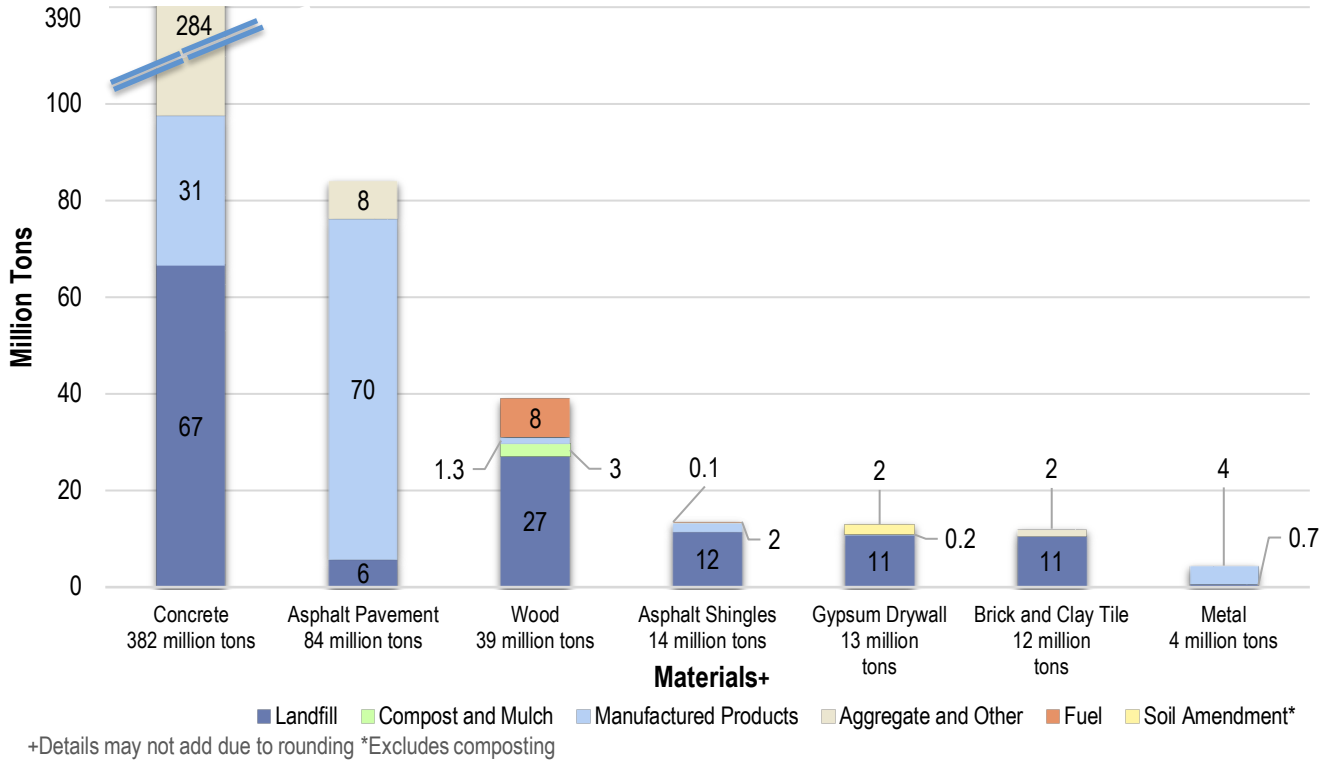
Table ES-1 is a summary of the total tonnages of each material type intended for next use destinations or sent to landfills. About 415 million tons were directed to next use and over 132 million tons of C&D debris were sent to landfills in 2015. "Aggregate" was the main EOL next use for C&D debris. This result is attributable to concrete, which is a heavy material and constitutes about 285 million tons and 97% of all C&D debris directed to aggregate.

Table ES-1. 2015 C&D Debris Sent to Landfills or Next Use (tons)

Material Type in C&D Debris	Landfill	Next Use					Total Next Use
		Compost and Mulch	Manufactured Products	Aggregate, Other	Fuel	Soil Amendment	
Concrete	66,535,034	0	30,962,635	284,260,331	0	0	315,222,966
Wood	27,053,922	2,611,131	1,296,159	0	7,988,787	0	11,896,078
Gypsum Drywall	10,803,717	0	234,675	0	0	2,003,608	2,238,283
Metal	670,495	0	3,784,505	0	0	0	3,784,505
Brick and Clay Tile	10,587,745	0	0	1,559,255	0	0	1,559,255
Asphalt Shingles	11,491,724	0	1,931,000	80,045	22,231	0	2,033,276
Asphalt Pavement	5,042,361	0	70,347,585	7,769,079	0	0	78,116,664
TOTAL	132,184,998	2,611,131	108,556,559	293,668,711	8,011,019	2,003,608	414,851,027

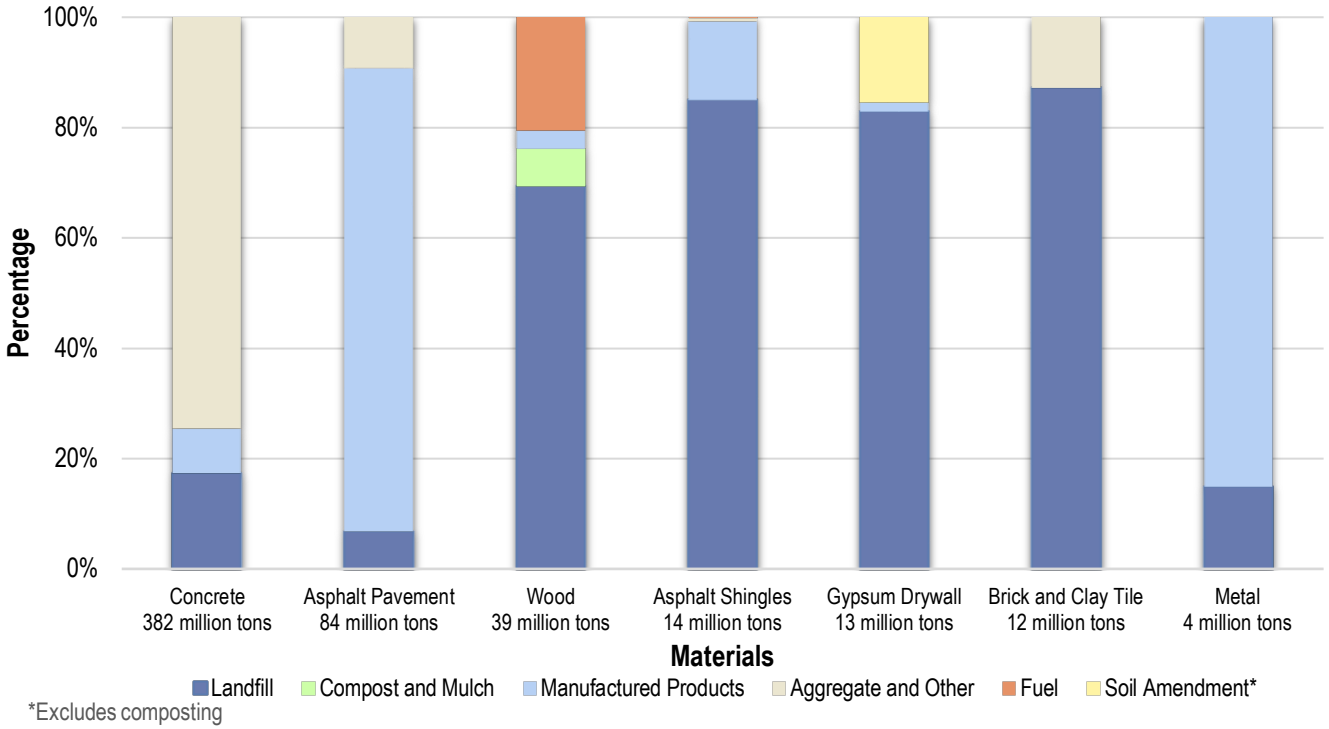
Figure ES-2, below, depicts quantities of a material in each destination in 2015. Materials are ordered according to their total generated tonnage, which for each material is noted at the bottom. The total generated tonnage of C&D concrete is two orders of magnitude larger than the tonnages of metal, gypsum drywall, asphalt shingles, and brick and clay tile. A break in the y-axis was needed to capture concrete as well as the other materials in the same chart. Keeping in mind that this break affects the visual representation of the tonnage of C&D concrete processed for use in aggregate, Figure ES-2 does indicate that the top three most prevalent end destinations for C&D materials include use in aggregate, landfills, and use in manufactured products. Figure ES-3 depicts quantities of a material in each destination as a fraction of the total generated amount for the material in 2015. The use in manufactured products was the dominant next use for asphalt concrete and metals. Aggregate was the main destination for C&D concrete. Landfills were the primary destination for C&D debris wood, gypsum drywall, brick and clay tile, and asphalt shingles.

Figure ES-2. 2015 C&D Debris Management by Activity (million tons)



+Details may not add due to rounding *Excludes composting

Figure ES-3. 2015 C&D Debris Management by Activity (percent of total generation amount for the material)



*Excludes composting

2.0 Detailed Methodology

The CDDPath provides a method to estimate the 2015 mass quantities of materials in the C&D debris stream intended for next use or directed to landfills. The CDDPath method is implemented in a series of sequential steps. For the purposes of this memo, an adjustment was made in the way these steps are implemented. Namely, the CDDPath method is defined in a manner that includes seven building materials for which EPA produced generation amounts in the C&D Debris Generation, 2015, memo, plus several other materials often managed along with them. The seven materials are:

- Steel
- Wood products
- Drywall and plaster
- Brick and clay tile
- Asphalt shingles
- Concrete
- Asphalt concrete

The other materials are plastic, glass, cardboard, organics, C&D fines, and carpet. Although the CDDPath provides a method for estimating these other materials, their estimates are excluded from this memo.

- Plastic, glass, cardboard, and carpet are excluded because they are routinely estimated in the SMM: Facts & Figures publications for the municipal solid waste (MSW) stream. Their estimation with the CDDPath method may have duplicated some fraction of estimates published in the *Advancing Sustainable Materials Management: 2015 Fact Sheet* (the "SMM: 2015 Fact Sheet") (EPA, 2018a) for the MSW stream. The extent of potential duplication will need to be assessed, and estimates reconciled.

- Organics, or the land clearing debris, are excluded because they are often managed outside the types of facilities that are the data sources for this memo. For example, land-clearing debris is often managed at the point of generation, on site, and such management is often not measured or reported. An omission of these amounts may have resulted in a significant underestimation of the total land-clearing debris. The extent of potential underestimation will need to be assessed.

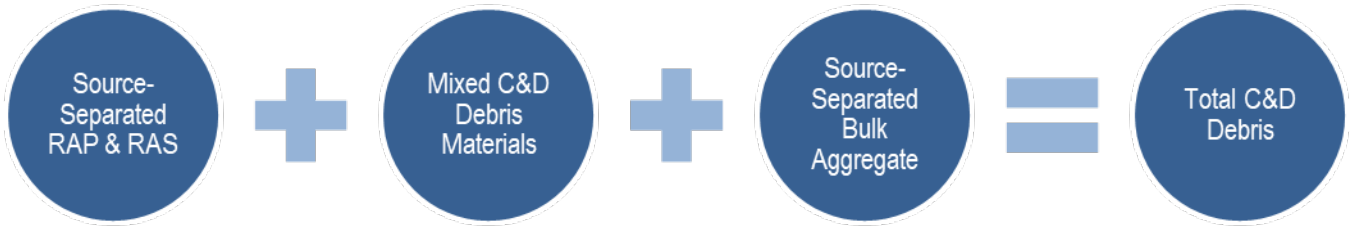
- C&D fines are excluded because they contain fragments of discrete materials, such as concrete, wood and drywall. These materials are already captured (as discrete materials) in the C&D Debris Generation, 2015, memo, and their generation estimates are entered in the CDDPath method. Counting these materials again, this time as C&D fines, would have resulted in double counting and inflation of the total generation amount. The extent of potential double counting will need to be assessed and reconciled.

Following is a detailed summary of the CDDPath steps relevant for calculations in this memo, providing explanation about how calculations were performed. However, equations are not included with every step. Further detailed lists of variables, equations, and explanations of CDDPath are included in Townsend et al. 2019.

Step 1: Define total C&D debris generation

C&D debris generation is defined as the sum of the generation amounts of source-separated reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS), mixed C&D debris materials, and source-separated bulk aggregate. Figure 1 illustrates the three main components of the C&D debris stream.

Figure 1. Main Components of the C&D Debris Stream



Step 2: Estimate RAP and RAS managed by the asphalt pavement industry along with each next use

Step 2 of the methodology references industry-provided values of source-separated asphalt pavement that was processed for next use or sent to landfills by the asphalt industry. The 2015 NAPA Survey provides a combined value for the total amount of RAP "accepted in a single year." This 2015 accepted amount does not equal the sum of the NAPA-published quantities sent to next use or landfills in 2015, due to the remaining inventory of RAP from prior years being stockpiled (NAPA 2017). EPA's methodology adjusts the RAP quantities sent to next use or landfills from the 2015 NAPA Survey (aggregate, hot, warm and cold mix asphalt, landfill, and other) such that their ratios to one another are preserved while their combined sum becomes equal to the 2015 accepted value. Moreover, the 2015 NAPA survey is also a source for defining a significant portion of the total RAS amount.

Additional quantities of RAP and RAS are managed in the mixed C&D debris. They are either processed for next use by state-permitted processing facilities and captured in the facility-level data in the CDRA Survey or sent to landfills as mixed C&D debris and captured in landfill composition studies. Therefore, no source fully accounts for all quantities of RAP and RAS intended for next use or sent to landfills, and the data from the 2015 NAPA Survey must be used in conjunction with the waste-composition and facility-level data to include all information while also correcting the overlap.[2]

Step 3: Estimate the preliminary composition of the next-use and landfill streams of mixed C&D debris

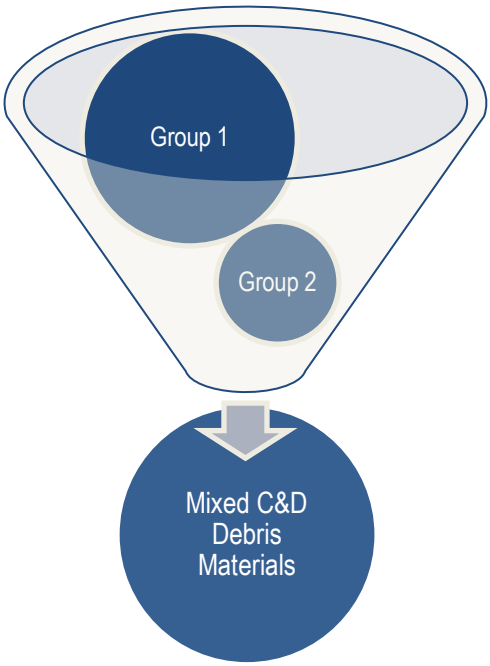
Step 3 begins to address the mixed C&D debris stream. Working from the sources of tonnage data for state-permitted C&D debris solid waste management facilities, Step 3 of the calculation develops preliminary fractions (percentage values) for mixed C&D material types within the next-use and landfill streams separately. Importantly, the entirety of the data from state-permitted C&D debris solid waste management facilities includes materials which are in this memo separately designated with "Group 1" and "Group 2" materials. Group 1 materials are six materials for which generation amounts were estimated in the C&D Debris Generation, 2015, memo by using a materials flow analysis (MFA) approach - steel, wood products, drywall and plaster, brick and clay tile, asphalt shingles, and concrete.[3] Group 2 materials are glass, organics, plastics, carpet, fines, cardboard, and the quantity of C&D asphalt concrete present in the mixed C&D debris stream. Information and data about

[2] EPA's methodology to include data from both sources and to adjust the overlap is explained in Step 9 of this memo.
[3] Note that in C&D Debris Generation, 2015, memo, the C&D asphalt concrete is not estimated using the MFA approach.

mass quantities of Group 2 materials landfilled or processed for next use were assembled from the state-reported data, landfill composition studies, and the CDRA Survey. Group 1 and Group 2 materials are often managed in state-permitted solid waste management facilities together, as mixed C&D debris, and as Figure 2 illustrates, the mixed-C&D-debris stream estimation is at this step focused on all of them.

Figure 2. Groupings of Materials in the Mixed C&D Debris

Group 1 materials were estimated in the C&D Debris Generation, 2015, memo using a materials flow analysis (MFA) approach, and are: steel, wood products, drywall and plaster, brick and clay tile, asphalt shingles, and concrete.



Group 2 materials are: glass, organics, plastics, carpet, fines, cardboard, and the quantity of C&D asphalt concrete managed in state-permitted solid waste management facilities as mixed C&D debris.

Step 4: Estimate the next-use and landfill totals for a representative material.

The purpose of Step 4 is to begin the process to determine the total sum quantities of mixed C&D debris sent to next use or landfills. In the absence of reported national totals, CDDPath must use a single, representative material to begin to quantify the mixed C&D debris streams. Wood is chosen as the representative material from which to begin estimating the mixed C&D debris.[4]

Three objectives were set for the representative material:

[4] Table S4 in the Supplementary Material of the *CDDPath: A method for quantifying the loss and recovery of construction and demolition debris in the United States* journal article (Townsend et al. 2019) provides an explanation of why C&D wood was chosen for the representative material.

1. First was data reliability. Example considerations for data reliability are ability to distinguish the material in the mixed stream, as well as that the measured data for the material are reported under a clear classification. Namely, a material that is fragmented beyond recognition is not measured correctly, and if a quantity of the material is included with several different materials under the same classification (e.g., various materials that are included under the classification of aggregate), the measured data is not specific to the material. In either case, the lack of reliable data would point to excluding such a material from consideration.

2. The second objective was that the representative material must have similar next-use and landfill rates as the mixed C&D debris stream overall. The national level next-use or landfill rates for individual materials in the mixed C&D debris are not easily developed, and in their absence, rates for the mixed C&D debris stream overall, must be used as a proxy (Eq. (1) and Eq. (2)). The closer the next-use and landfill rates for the material and the stream are, the more defensible the use of the proxy.

3. Finally, quantities of mixed C&D materials that are estimated starting from the representative material will in the next step be compared to the generation amounts in the C&D Generation, 2015, memo. The better aligned these quantities are, the greater the confidence in the choice of the representative material.

Why use C&D wood as a representative material?

C&D wood met objectives defined for a representative material better than other materials in the mixed C&D stream.

1. Data reliability. E.g., wood is
   - Easy to identify in the stream; and,
   - Measured data are reported in a discrete, unambiguous category.
2. Wood is sent to next use or landfills at similar rates as the overall mixed C&D debris stream.
3. Ensuing estimates for the remaining mixed-C&D-debris materials are close to generation amounts in the C&D Debris Generation, 2015, memo.

Townsend et al. 2019. Supplementary Material, Table S4.

Mass quantities of C&D wood intended for next use or sent to landfills are estimated by assuming that wood is sent to next use or landfills at approximately the same rates as the overall mixed C&D debris stream. The next-use (i.e., material recovery) and landfill rates for mixed C&D debris overall, are applied to the C&D wood generation amount from the C&D Debris Generation, 2015, memo. These next-use and landfill rates for mixed C&D debris are developed from data for states reporting total quantities of both mixed C&D debris intended for next use and sent to landfills.

Eq. (1) estimates the amount of C&D wood intended for next use in the US annually, $CDD_{W,R.}$. Eq. (2) estimates the amount of C&D wood sent to landfill, $CDD_{W,LF}$.

$$CDD_{W,R} = \frac{CDD_{R-RS}}{CDD_{R-RS}+CDD_{LF-RS}} \times CDD_W \quad (1)$$

$$CDD_{W,LF} = \frac{CDD_{LF-RS}}{CDD_{R-RS}+CDD_{LF-RS}} \times CDD_W \quad (2)$$

CDD_W is the amount of wood from the C&D Debris Generation, 2015, memo; $CDD_{LF\text{-}RS}$ is the total mixed C&D debris sent to landfills in states reporting total quantities of both mixed C&D debris intended for next use and sent to landfills; and, $CDD_{R\text{-}RS}$ is the total mixed C&D debris intended for next use in the same reporting states.

Step 5: Estimate preliminary total amounts of landfill or next use for MFA components.

Group 1 materials are at this step separated from Group 2 materials for two reasons. Group 1 materials are steel, wood products, drywall and plaster, brick and clay tile, asphalt shingles, and concrete. Group 2 materials are glass, organics, plastics, carpet, fines, cardboard, and the quantity of C&D asphalt concrete present in the mixed C&D debris stream.

1. Final landfill and next-use estimates can initially only be developed for Group 1 materials. Landfill and next use quantities of these materials are estimated by applying preliminary composition fractions from Step 3. These preliminary fractions are developed based on average measured data and composition fractions from a sample of states, localities, and facilities. The representation of states, localities, and facilities in those averages biases extrapolations of these measured data onto the country, and results are therefore, considered preliminary.

   At the same time, national-level generation quantities were independently estimated for Group 1 materials, using an MFA approach. The MFA estimates rely on national-level data about material flows through the U.S. economy. They are produced based on a mass-balance view of an industry sector and are therefore, expected to show the amount of a material that "should have been" generated within the sector across the entire country. Using generation estimates to adjust preliminary estimates that were developed from averages of a limited number of states, localities, and facilities, is therefore, appropriate.

   Sums of preliminary landfill and next-use quantities can be set to equal the national-level generation amounts that were independently developed using the MFA approach. When these preliminary landfill and next-use estimates are adjusted so their sum would equal the published MFA generation amounts, they become final.

2. Final estimates for Group 2 materials must be developed from final estimates of Group 1 materials. In the absence of MFA generation estimates for Group 2 materials, a similar adjustment as the one for Group 1 cannot be performed for Group 2 materials. Therefore, landfill and next-use estimates for Group 2 materials cannot be made final using the same process. However, the separation of materials into Group 1 and Group 2, aggregates materials into two fractions of the mixed C&D debris stream; the sequential estimating of Group 1 followed by Group 2 materials allows Group 2 materials to be extrapolated from Group 1 materials once Group 1 estimates are made final.

In Step 5, preliminary fractions from Step 3 are normalized to Group 1 materials, so that the Group 1 materials now constitute 100% of the estimation universe and can be examined separately. Estimates of C&D wood intended for next-use or sent to landfills (defined in Step 4) are divided by the normalized fractions of wood. These calculations produce preliminary sum quantities (tons) of Group 1 materials sent to next use, (Eq. (3)); and Group 1 materials sent to landfills, (Eq. (4)).

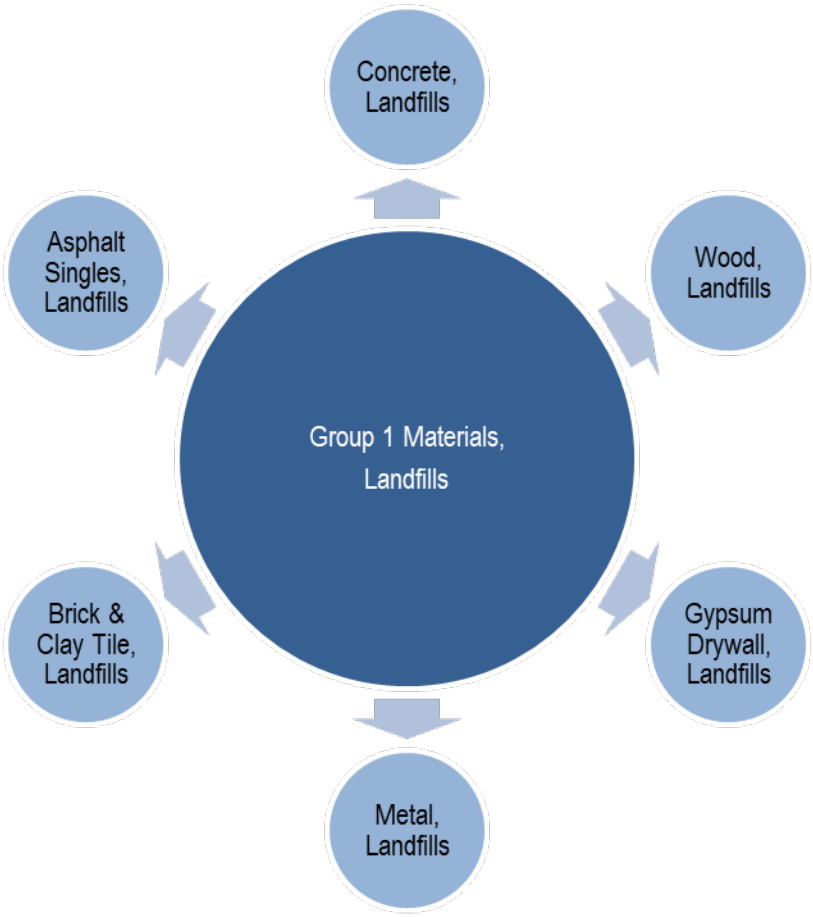
$$CDD_{Mx-MFA,R,Pre} = \frac{CDD_{w,R}}{f_{w,MFA,R}} \quad (3)$$

$$CDD_{Mx-MFA,LF,Pre} = \frac{CDD_{w,LF}}{f_{w,MFA,LF}} \quad (4)$$

$CDD_{W,R}$ *is* the quantity of wood intended for next use; and $f_{w,MFA,R}$ is the fraction of wood from the CDRA Survey, normalized using the total fraction of Group 1 materials in the CDRA Survey. $CDD_{w,LF}$ is the total quantity of wood sent to landfills; and $f_{w,MFA,LF}$ is the fraction of C&D wood in the average of landfill composition studies, normalized by the total fraction of Group 1 materials in the composition studies.

Once preliminary sum quantities (tons) of Group 1 materials intended for next use and Group 1 materials sent to landfills are estimated, they can be apportioned to each material in the group by applying the normalized fraction for the material. The result are preliminary quantities of each Group 1 material, sent to next use (Eq. (5)) or landfills (Eq. (6)). Figure 3 illustrates this apportionment on the side of Group 1 materials sent to landfills.

Figure 3. Apportionment of Preliminary Quantity of Group 1 Materials Sent to Landfills



$$CDD_{x-MFA,R,Pre} = \frac{f_{x,R}}{f_{MFA,R}} \times CDD_{Mx-MFA,R,Pre} \quad (5)$$

$CDD_{x-MFA,R,Pre}$ is the preliminary quantity of a material x (in Group 1 materials) sent to next use; $\frac{f_{x,R}}{f_{MFA,R}}$ is the fraction of material x from the CDRA Survey, normalized using the total fraction of Group 1 materials in the CDRA Survey; and, $CDD_{Mx-MFA,R,Pre}$ is the preliminary sum quantity of Group 1 materials sent to next use.

$$CDD_{x-MFA,LF,Pre} = \frac{f_{x,LF}}{f_{MFA,LF}} \times CDD_{Mx-MFA,LF,Pre} \quad (6)$$

$CDD_{x-MFA,LF,Pre}$ is the preliminary quantity of a material x (in Group 1 materials) sent to landfills; $\frac{f_{x,LF}}{f_{MFA,LF}}$ is the fraction of material x in the average of landfill composition studies, normalized by the total fraction of Group 1 materials in the composition studies; and $CDD_{Mx-MFA,LF,Pre}$ is the preliminary sum quantity of Group 1 materials sent to landfills.

Next, the sum of preliminary quantity sent to next use and landfills is for each material set to equal the generation amount from the C&D Debris Generation, 2015, memo. In cases where the sum is not identical, the preliminary landfilled quantity is adjusted to account for the discrepancy. The assumption behind that decision is that the next use composition data are based on a more representative sample than the landfill data, and that therefore, the next use quantities should be retained while landfill quantities are adjusted. The adjusted values are final.

Step 6: Estimate total MFA waste components in mixed C&D debris.

A simple sum of the Step 5's final adjusted C&D debris material quantities sent to next use or landfills, produces the total final sum quantity of the Group 1 materials sent to next use and the total final sum quantity of the Group 1 materials sent to landfills. The sum quantity of the Group 2 materials can be extrapolated from the sum quantity of the Group 1 materials now that the sum Group 1 materials are made final.

Step 7: Estimate total non-MFA components in mixed C&D debris.

In Step 7, preliminary fractions from Step 3 are normalized to Group 2 materials, so that the Group 2 materials now constitute 100% of the estimation universe and can be examined separately. The Group 2 materials are glass, organics, plastics, carpet, fines, cardboard, and a quantity of C&D asphalt concrete in the mixed C&D debris stream. For this memo, only the quantity of C&D asphalt concrete is of interest. However, to derive that estimate, the sum quantity of Group 2 materials must be developed and then disaggregated to asphalt concrete.

Sum quantities of Group 2 materials are extrapolated from sum quantities of Group 1 materials. Preliminary fractions (percentage values) for mixed C&D material types within the landfill and next-use streams were calculated in Step 3. Ratios of cumulative sum fractions of Group 2 over Group 1 materials are used as a multiplication factor to calculate the total sum quantities of Group 2 materials.

Eq. (7) describes the sum quantity of Group 2 materials sent to next use, $CDD_{Mx,Non-MFA,R}$.

$$CDD_{Mx,Non-MFA,R} = \frac{f_{Mx,Non-MFA,R}}{f_{Mx,MFA,R}} \times CDD_{Mx,MFA,R} \quad (7)$$

$f_{Mx,MFA,R}$ is the fraction of the next use mixed-C&D-debris stream comprised of Group 1 materials, while $f_{Mx,Non-MFA,R}$ is the fraction comprised of Group 2 materials. $CDD_{Mx,MFA,R}$ is the final quantity of Group 1 materials sent to next use, as calculated in Step 6.

Similarly, Eq. (8) describes the sum quantity of Group 2 materials sent to landfills, $CDD_{Mx,Non-MFA,LF}$.

$$CDD_{Mx,Non-MFA,LF} = \frac{f_{Mx,Non-MFA,LF}}{f_{Mx,MFA,LF}} \times CDD_{Mx,MFA,LF} \quad (8)$$

$f_{Mx,MFA,LF}$ is the fraction of the landfill mixed-C&D-debris stream comprised of Group 1 materials, while $f_{Mx,Non-MFA,LF}$ is the fraction comprised of Group 2 materials. $CDD_{Mx,MFA,LF}$ is the final quantity of Group 1 materials sent to landfills as calculated in Step 6.

The normalized fractions of C&D asphalt concrete sent to next use or landfills are then applied to the total sum quantity of Group 2 materials sent to next use (Eq. (7)) or landfills (Eq. (8)). The resulting quantities of C&D asphalt sent to next use and sent to landfills are summed up and added to the "accepted" 2015 RAP tonnage from Step 2. The final sum quantity constitutes the C&D asphalt concrete generation amount published in the C&D Debris Generation, 2015, memo.

Step 8: Estimate quantities of bulk aggregate intended for next use or landfill

The focus of Step 8 is on determining quantities of bulk aggregate. C&D brick and clay tile, and concrete are managed in both state-permitted C&D debris solid waste management facilities as well as bulk aggregate facilities. The amounts of these materials sent to landfills or processed for next use in state-permitted solid waste management facilities are calculated in Step 5. Sums of quantities sent to landfills or next use as part of mixed C&D debris are at Step 5 compared against the generation amounts in the C&D Debris Generation, 2015, memo. The comparison at this step produced a difference only for concrete, and this difference is assumed to be the amount of source-separated C&D concrete managed as bulk aggregate. CDRA provides an industry-specified 85% recycling factor for the source-separated C&D concrete (Townsend et al. 2014). That fraction is applied to the source-separated C&D concrete and the resulting value represents the source-separated concrete sent to next use. The remainder, 15%, is also applied to determine the source-separated concrete sent to landfills.

Step 9: Determine material quantities in each next use

Lastly, fractions of specific next uses for each material from the CDRA Survey are applied to total quantities of a material in next use. Using and applying these fractions for each material divides the quantity intended for next use across specific next-use markets.

Eq. (9) describes the total annual mass of C&D material *i* sent to next use market *p*.

$$CDD_{i,p} = CDD_i \times f_{i,p} \quad (9)$$

Here, CDD_i represents the quantity of material i sent to next use; and, $f_{i,p}$ is the fraction of material *i* sent to next use market *p*.

Step 9 divides a material's quantity intended for next use across specific next use markets. Final quantities of C&D debris materials directed to landfills were estimated in earlier steps (Step 5 for the mixed C&D debris materials, Step 2 and Step 7 for C&D asphalt concrete, and Step 8 for bulk aggregate). Having estimated quantities of materials sent to landfills and the distribution across specific next uses for a material, the implementation of the methodology is generally concluded. However, due to the data overlap for asphalt shingles

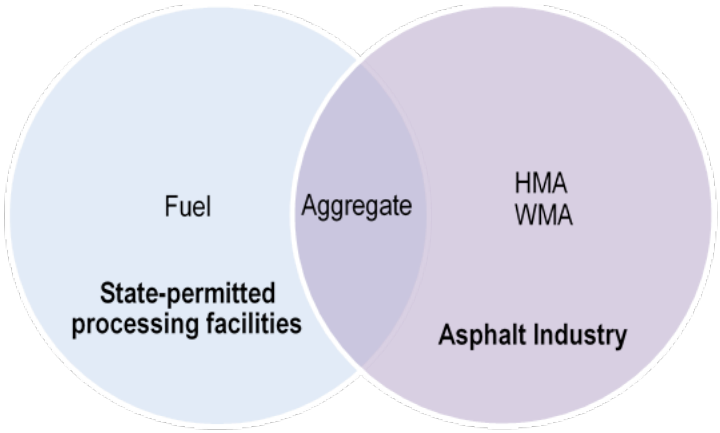
between the 2015 NAPA survey and the state-permitted processing facilities, Step 9 conducts an additional adjustment to reconcile asphalt-shingle calculations in Step 2 with calculations in Step 5.

C&D Asphalt Shingles

C&D asphalt shingles are managed at EOL in the asphalt industry and in state-permitted solid waste management facilities. Step 2 and the 2015 NAPA Survey helped estimate quantities of shingles that were directed by the asphalt industry to hot-mix asphalt (HMA), warm-mix-asphalt (WMA) and aggregate markets. Step 9 and the CDRA Survey helped estimate shingles that were processed and directed by state-permitted processing facilities to HMA, WMA, aggregate and fuel markets.

The "fuel" total from state-permitted processing facilities is retained. The "HMA" and "WMA" totals from the 2015 NAPA Survey are retained under the assumption that the asphalt industry receives and handles all shingles processed for HMA and WMA. The "aggregate" total from processing facilities is added to the "aggregate" total from the 2015 NAPA Survey under the assumption that the asphalt industry does not receive and handle all shingles processed for aggregate. Figure 4 summarizes and illustrates the data sources used for quantities in each of these next uses. (Note that the diagram is not meant to represent that aggregate quantities reported by state-permitted processing facilities and asphalt industry are the same; rather, it is meant to show that both sources report values for aggregate, and both values are used.) Finally, the sum of the quantities for fuel, HMA, WMA and aggregate next uses, is subtracted from the generation amount in the C&D Debris Generation, 2015, memo to obtain the quantity of asphalt shingles sent to landfills.

Figure 4. Data Sources Used to Estimate Quantities of C&D Asphalt Shingles in Specific Next Use Markets



3.0 Results

Provided below is a summary of the total tonnages by each material type and end destination. Table 1 shows about 415 million tons were directed to next use and over 132 million tons of C&D debris were sent to landfills in 2015.

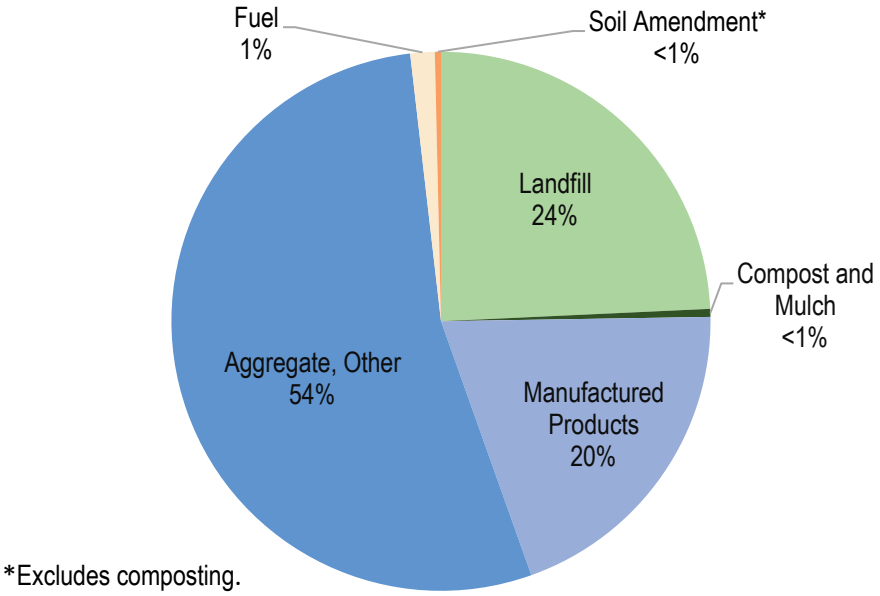
Figure 5 shows the end destinations, i.e., next-use markets or landfills, with the percent of the total C&D debris amount directed to those destinations. Figures 6-11 show fractions of C&D debris materials in each next use.

Table 1. 2015 C&D Debris Sent to Landfills or Next Use

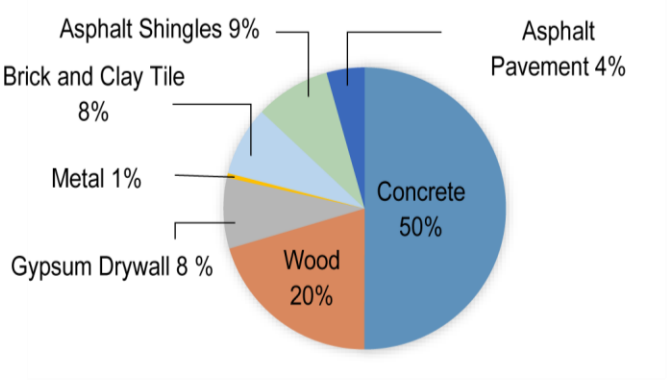
Material Type in C&D Debris	Landfill	Next Use					Total Next Use
		Compost and Mulch	Manufactured Products	Aggregate, Other	Fuel	Soil Amendment	
Concrete	66,535,034	0	30,962,635	284,260,331	0	0	315,222,966
Wood	27,053,922	2,611,131	1,296,159	0	7,988,787	0	11,896,078
Gypsum Drywall	10,803,717	0	234,675	0	0	2,003,608	2,238,283
Metal	670,495	0	3,784,505	0	0	0	3,784,505
Brick and Clay Tile	10,587,745	0	0	1,559,255	0	0	1,559,255
Asphalt Shingles	11,491,724	0	1,931,000	80,045	22,231	0	2,033,276
Asphalt Pavement	5,042,361	0	70,347,585	7,769,079	0	0	78,116,664
TOTAL	132,184,998	2,611,131	108,556,559	293,668,711	8,011,019	2,003,608	414,851,027

"Aggregate" was the main EOL next use for C&D debris (Figure 5). This result is attributable to concrete, which is a heavy material and constitutes about 285 million tons and 97% of all C&D debris directed to aggregate (Table 1, Figure 9). The next most prevalent end destination was landfill, at 24% of the total amount of C&D debris (Figure 5). Landfilled at the amount of about 66 million tons, concrete represented 50% of the C&D debris sent to landfills (Table 1 and Figure 6). The "manufactured products" next use followed at 20% of the total generated C&D debris amount (Figure 5). About 70 million tons of C&D asphalt pavement were incorporated in manufactured products, constituting 65% of the total C&D debris amount processed for this use (Table 1, Figure 8). The remaining 2% of the total C&D debris amount was directed to use in fuel, compost and mulch, and soil amendment.

Figure 5. 2015 End Destinations for C&D Debris (percent of total)

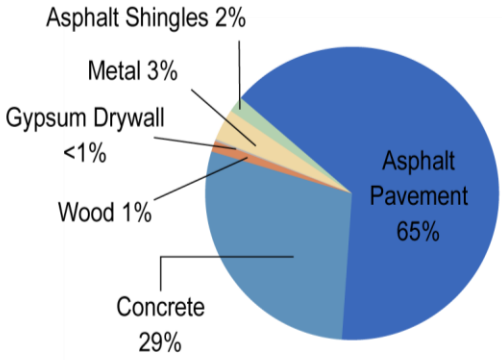


Figures 6 through 11. 2015 Estimated C&D Debris Composition at End Destination

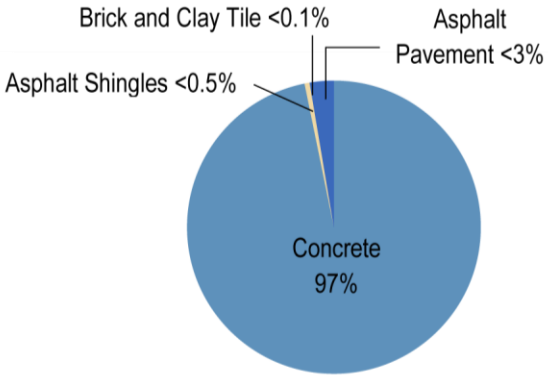


Landfill

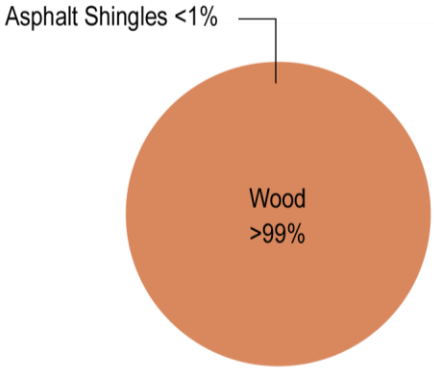
Compost and Mulch



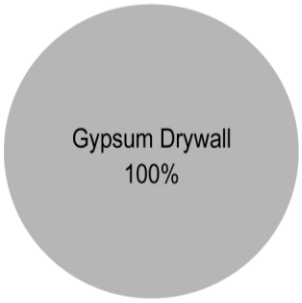
Manufactured Products



Aggregate and Other



Fuel



Soil Amendment

Figure 12 depicts quantities of a material in each destination in 2015. Materials are ordered according to their total generated tonnage, which for each material is noted at the bottom. The total generated tonnage of C&D concrete is two orders of magnitude larger than the tonnages of metal, gypsum drywall, asphalt shingles, and brick and clay tile. A break in the y-axis was needed to capture concrete as well as the other materials in the same chart. Keeping in mind that this break affects the visual representation of the tonnage of C&D concrete processed for use in aggregate, Figure 12 does further indicate that the top three most prevalent end destinations for C&D materials include use in aggregate, landfills, and use in manufactured products.

Figure 12. 2015 C&D Debris Management by Activity (million tons)

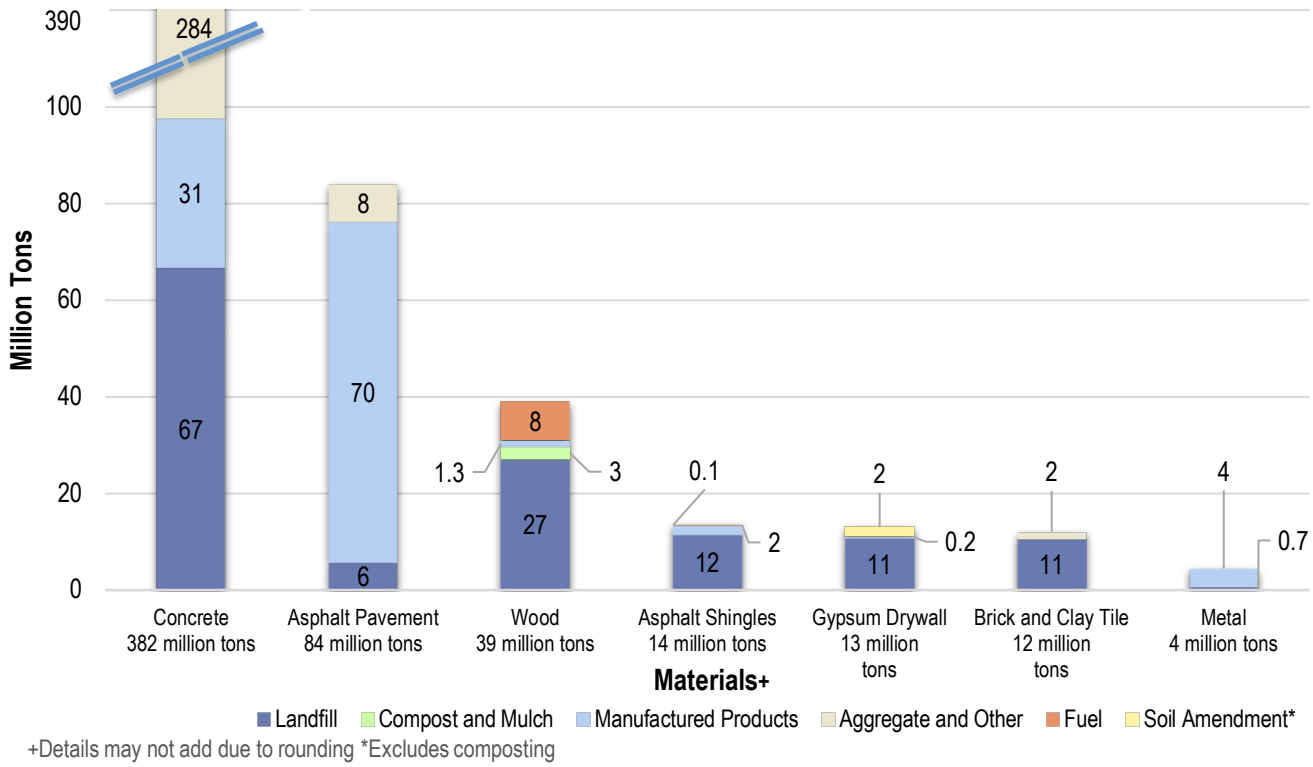
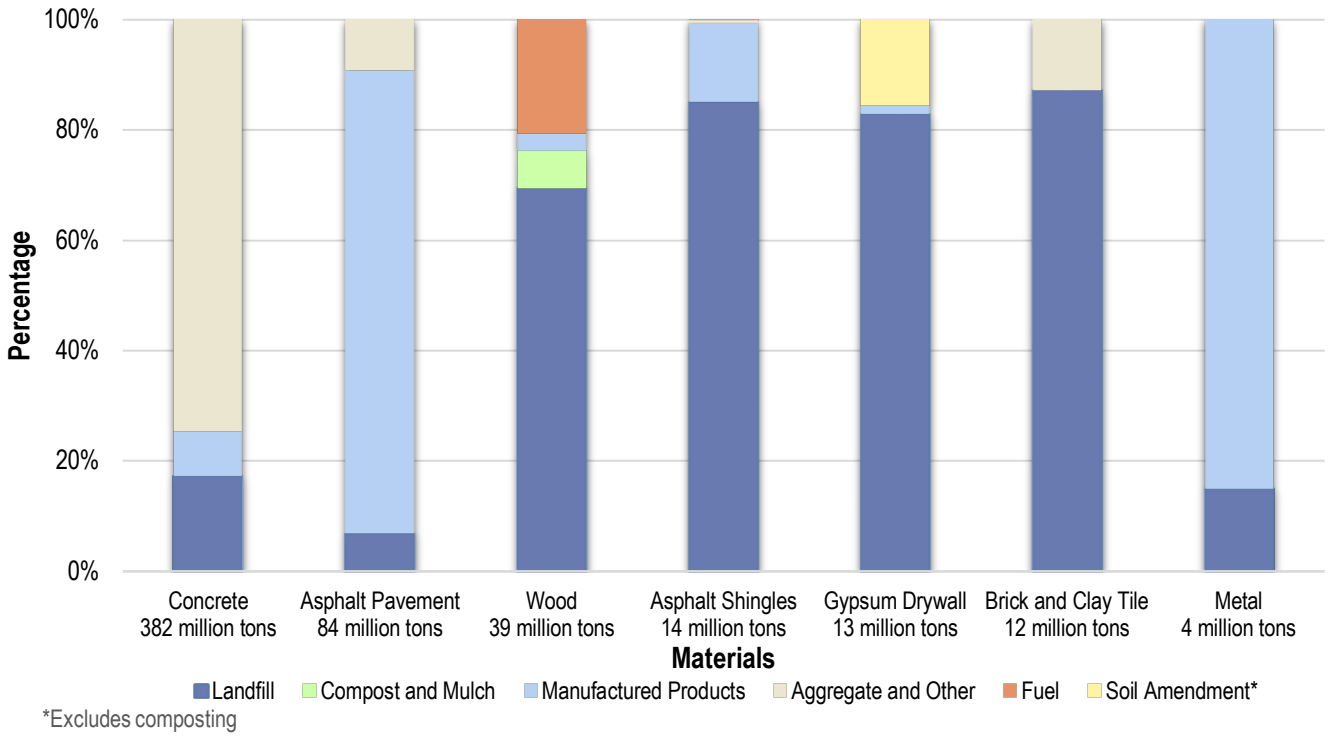


Figure 13 depicts the quantities of a material in each destination as a fraction of the total generated amount for the material in 2015. The use in manufactured products was the dominant next use for asphalt concrete and metals (over 80% each, though the tonnage amounts that those percentages correspond to are very different for the two material types). Aggregate was the main destination for C&D concrete (over 70%). Landfills were the primary destination for C&D debris wood, gypsum drywall, brick and clay tile, and asphalt shingles, accounting for 70% or more of the generated quantity of each.

Figure 13. 2015 C&D Debris Management by Activity (percent of total generation amount for the material)



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Appendix: Data Sources

This appendix describes the data sources used in calculations described in EPA's memo, *Construction and Demolition Debris Management Pathways in the United States, 2015*.

A.1 Total C&D Debris Generation

EPA estimated the 2015 C&D concrete, wood products, drywall and plasters, steel, brick and clay tile, and asphalt shingles generation amounts shown in Table A.1 based on a materials flow analysis (MFA) (EPA 2018). These generation amounts are used as a data input.

The estimate of the generation amount of C&D asphalt concrete was produced in this memo based on the EOL management data. The data sources included the National Asphalt Pavement Association (NAPA) with the data about the amount of RAP accepted by asphalt producers and the state-permitted solid waste management facilities with the data about the facility-based management. The NAPA data and the state-permitted facility data are data inputs, but the C&D asphalt concrete generation amount is an output of this memo. Table A.1 also presents the calculated sum amount of C&D asphalt concrete.

Table A.1. C&D Debris Generation by Material for 2015 (tons)

C&D Material Type	2015 (tons)
Concrete	381,758,000
Wood Products	38,950,000
Gypsum Drywall & Plasters	13,042,000
Steel	4,455,000
Brick and Clay Tile	12,147,000
Asphalt Shingles	13,525,000
Asphalt Concrete	83,900,000
Total	**547,777,000**

A.2 2015 NAPA Survey

The NAPA Survey is an annual, industry-led survey of U.S. based asphalt pavement companies. The extensive report estimates annual values for the total amount of reclaimed asphalt pavement (RAP) accepted by asphalt pavement companies, as well as the fractions sent to landfill or next use (e.g., hot, warm or cold mix asphalt and aggregate). The NAPA Survey also provides information about EOL management of recycled asphalt shingles (RAS) accepted by asphalt producers. Table A.2 summarizes the data in the 2015 NAPA Survey that were used for calculations described in this memo.

Table A.2. NAPA Survey Data for 2015 (tons)

NAPA Survey Category	2015	
	Unadjusted*	Adjusted*
RAP accepted	78,000,000	
RAP Destination		
Aggregate	5,500,000	5,200,000
HMA/WMA	74,200,000	70,152,727
CMA	200,000	189,091
Other	1,600,000	1,512,727
Landfill	1,000,000	945,455
RAS Destination		
Aggregate	9,000	^
HMA/WMA	1,931,000	^
CMA	0	^
Other	0	^
Landfill	0	^

* The 2015 accepted amount does not equal the sum of the NAPA published management destinations in 2015 due to the remaining inventory of RAP from prior years being stockpiled (NAPA 2017). The RAP destinations (aggregate, hot, warm (HMA/WMA) and cold mix asphalt (CMA), other and landfills) are adjusted such that their ratios to one another are preserved while their combined sum becomes equal to the 2015 accepted value.
^ RAS data are not adjusted for use in the methodology.

A.3 State-Level C&D Debris End-of-Life Management Data

State-level C&D debris EOL management data are used as input in Step 4 of the CDDPath methodology to help calculate C&D debris next-use and landfill rates. Eighteen states provide state-issued publications and/or report in the State Measurement Program (SMP) information about C&D debris management in the state. The latter is a web-based database that allows for simple submission of numerical data, but it contains relatively little interpretative or guiding language. Table A.3 shows the combined data from the states that were used for input in the 2015 EOL management calculations described in this memo.

Table A.3. State-Level C&D Debris Landfilled and Processed Data (tons)

State	Source Used in 2015 Analysis	Data Year Used
FL	SMP	2015
ME	Maine DEP (2017)	2015
MA	Massachusetts EEA (ND)	2015
MD	Maryland DOE (2015)	2013
NV	SMP	2015
PA	SMP	2013
TX	Texas CEQ (2016)	2015
VA	Virginia DEQ (2016)	2015
WA	Washington Department of Ecology (2017)	2014
GA	SMP	2015
HI	City and County of Honolulu DES (2017)	2015
IL	Illinois Department of Commerce and Economic Opportunity (2015)	2014
NC	Re-TRAC, North Carolina DEQ (ND)	2015
SC	S.C. DHEC (2016)	2015
TN	SMP	2015
VT	State	2015
IN	SMP	2015
MS	SMP	2015
	Combined Disposed (tons)	Combined Processed (tons)
	39,422,897	**17,411,610**
Fraction of Total	**69.36%**	**30.64%**

State-level next-use and landfill rates are used at the start of the calculation for mixed C&D debris materials and are the basis for determining variables in several successive steps of the CDDPath methodology.

EPA used its best judgment in including state data sets that seemed to provide the greatest completeness, reasonableness, and year-to-year consistency. In addition, our data quality criteria required incorporating state data where both next use and landfill tonnages were available.

A.4 C&D Debris Landfill Waste Composition Studies

The composition studies that estimate the composition of the C&D debris sent to landfills are used as input into Step 3. The effort to identify relevant landfill waste composition studies included a broad internet search of state and regional sources. Key criteria for including a study were a tonnage-based reporting system (i.e., composition data could not be shown by percent faction only), regional diversity, and adequate granularity of the material types. Studies which met the geographic and reporting requirements, but lacked material types needed to apply

the CDDPath methodology were discarded. The five compositional studies shown in Table A.4 were used for input in the calculations described in this memo.

Table A.4. State-Level Landfill Composition Studies

Report	Data Year	State/Region	Non-zero material types	Reference
2015-2016 Statewide Waste Characterization Study	2015/2016	Washington	10	Washington Department of Ecology (2016)
Construction and Demolition Waste Characterization and Market Analysis	2013	Connecticut	8	Department of Energy and Environmental Protection (2016)
Detailed Characterization of Construction and Demolition Waste	2005	California	10	California Environmental Protection Agency (2006)
Illinois Commodity/ Waste Generation and Characterization Study	2014	Illinois	10	Illinois Recycling Association (2015)
Statewide C&D Debris Characterization Study (GA)	2008/2009	Georgia	10	Georgia Department of Natural Resources (2010)

Table A.5 shows percentages of material types in the C&D debris sent to landfills based on the five compositional studies. Percentages were derived as the ratio of tons of C&D material types landfilled and total C&D debris landfilled across the states.

Table A.5. Composition of Landfilled Waste from Five Compositional Studies

Material Category	2015
Asphalt	4.28%
Concrete	11.31%
Fines	6.84%
Wood	22.53%
Roofing	17.47%
Gypsum	7.39%
Organics	1.70%
Metal	3.11%
Other Materials	17.46%
Other Aggregates	7.81%

Source: Townsend et al. 2018

A.5 C&D Debris Next-Use Markets

The processed tonnages by destination, which are used in converting material tonnage to individual next use tonnages, are derived from data compiled through an industry-led effort (CDRA 2014) (Townsend et al. 2018). The Construction and Demolition Recycling Association (CDRA) coordinates updates of this dataset. The data from CDDPath were fully adopted for this 2015 analysis from the published CDDPath dataset (Townsend et al. 2018).