The Benefits of Construction and Demolition Materials Recycling in the United States

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Executive Summary

Construction and demolition materials (C&D) are recognized as one of the largest components of the solid waste stream in the US. While much of this material is recycled for purely economic reasons, avoidance of landfill disposal of materials such as concrete, wood, gypsum drywall and asphalt shingles has benefits well beyond financial ones. C&D materials recycling results in a greater job creation and industrial activity relative to landfilling. Avoidance of landfilling also provides for a greater degree of environmental protection, a smarter use of natural resources, energy savings, and a net decrease in greenhouse gas emissions. This report summarizes an effort conducted to assess the benefits of the C&D recycling industry in the US. The numerical estimates presented herein were determined using available C&D industry data from the literature, additional information surveyed from the C&D recycling community, and the authors' professional experience.

C&D generation statistics are not rigorously tracked in the US, and predictions of the amount of C&D landfilled and recycled vary dramatically. For this analysis, the amount of C&D generated in the US in 2012 was estimated at approximately 480 million tons. The C&D consists of approximately 100 million tons of mixed C&D, 310 million tons of bulk aggregate (primarily concrete), and 70 million tons of reclaimed asphalt pavement (RAP). Over 70% of this waste stream was projected as being recovered and put to beneficial use by the C&D recycling industry (corresponding to a 35% recycling rate for mixed C&D, an 85% recycling rate for bulk aggregate, and an over 99% recycling rate for RAP). The area of landfill avoided by recycling this amount of C&D is equivalent to over 4,300 acres (at a waste depth of 50 ft).

The energy savings and greenhouse gas (GHG) emissions avoidance as a result of recycling C&D components instead of landfilling them was assessed using emission and energy factors developed by the US Environmental Protection Agency. In 2012, the estimated magnitude of GHG emissions offset corresponded to taking 4.7 million passenger cars off the road for an entire year. The energy savings resulting from C&D recycling was equivalent to over 85 million barrels of oil.

Using industry survey results and the waste recycling projections, the C&D recycling industry was projected to be responsible for the direct support of 19,000 jobs in the US in 2012. Facility owners have invested over $4.5 billion in the development and construction of C&D recycling infrastructure. The direct annual output (revenue) of the C&D recycling industry was estimated to be approximately $7.4 billion, and when considering indirect and induced economic output, the industry represented an over $17 billion contribution.

1.0 Introduction

Construction and demolition (C&D) materials consist of the debris generated during the construction, renovation, and demolition of buildings, roads, and bridges. C&D represents one of the largest components of the solid waste stream in the United States. The most common components of C&D include concrete, asphalt, wood, gypsum drywall, asphalt shingles, metals, ceiling tiles and carpet. Other components may include cardboard, bricks, glass, plastics, salvaged building components (doors, windows, and plumbing fixtures), and trees, stumps, earth, and rock from clearing sites. Historically, a large amount of C&D has been disposed of in landfills, but in recent decades a vibrant industry has evolved centered on the recycling and recovery of the resources contained within C&D. Today in the US, C&D materials are used as substitutes for virgin materials in construction projects, raw ingredients for new product manufacture, and fuels for energy production.

The benefits of recycling are now widely recognized by the public, and participation in local recycling programs has become a way of life for most US citizens. These efforts focus on familiar components of our municipal waste stream such as plastic, glass and metals containers, and paper and cardboard products from printed documents and packaging materials. Municipalities promote the benefits accrued through recycling, including savings in natural resources, decreased dependence on landfills, energy savings, and environmental benefits. Unbeknownst to the average person, however, is the similarly large benefit resulting from recycling C&D.

This report, prepared on behalf of the Construction & Demolition Recycling Association (CDRA), attempts to quantify the benefits of C&D recycling in US. The benefits examined include energy savings, reduction in landfill disposal volumes, job creation, economic productivity and return to local communities, and reduction in greenhouse gas emissions. The resulting benefit estimates correspond to the 2012–13 time frame and rely on a variety of data sources, including existing literature and industry statistics, US EPA energy and emission estimates for recycled materials, and a survey of C&D industry members. Statistics on the amount and disposition of C&D in the US are limited, and thus the authors were required to make a number of assumptions using the available data and their professional judgment.

2.0 C&D in the US

Statistics regarding C&D characteristics and management in the US have not been tracked in the same detail as municipal solid waste (MSW). Necessary for any calculation of C&D recycling benefits, however, is an estimate of the total amount of C&D recycled, including recycled amounts by major component category (e.g., concrete, wood, etc.). While some states provide C&D generation and recycling information based on facility-reported data, most states do not, thus measured data cannot be used for this estimate (this data can be used for some parts of the estimate). The following two sub-sections summarize the estimates for US C&D generation and recycling used in later benefit estimates.

2.1 C&D Generation

The US EPA commissioned Franklin Associates to development an estimate of 1996 C&D generation in the US. This study utilized national Census Bureau data on construction industry project activity along with point source waste assessment data (such as waste sampling and weighing at a variety of construction and demolition sites) to estimate the amount of C&D produced nationally. This evaluation only included building-related debris (road and bridge debris was not included), and estimates were made for the following C&D categories: residential construction, residential demolition, residential renovation, nonresidential construction, nonresidential demolition, and nonresidential renovation. The resulting C&D estimate was 135.5 million tons of building-related C&D (10.8, 59.9, and 64.8 million tons of construction, renovation, and demolition debris, respectively). As part of this report, the amount of C&D recycled in the US was estimated in the range of 30% to 40%.

The US EPA conducted an updated C&D generation study for 2003 following a similar methodology as the 1996 approach, and still focused on building-related C&D. The resulting C&D estimate was 170 million tons of building-related C&D (15, 71, and 84 million tons of construction, renovation, and demolition debris, respectively). In this report, the amount of C&D recycled in the US was estimated at approximately 48%.

Cochran and Townsend (2010) utilized an alternative methodology for estimating US C&D generation in 2002, a materials flow analysis (MFA). The MFA approach uses historic national production and usage data for a material or product (e.g., tons of concrete or wood used in building construction in a year), and based on average material or product lifetimes, estimates waste generation for that component. The Cochran and Townsend estimate included both building debris as well as road, bridge and other structure debris, and examined the following material categories: portland cement concrete, wood, drywall, asphalt shingles, steel, brick, and asphalt concrete. The resulting C&D estimate ranged from 670–860 million tons in 2002, with 120–240 million tons originating from building-related C&D and the remainder from road, bridge and other structures.[1]

For the current evaluation, a new C&D generation estimate was developed corresponding to the time frame of 2012–2013. The generation estimate relied on the Cochran and Townsend MFA approach, but was modified to develop individual estimates for three specific C&D categories: mixed C&D, bulk aggregate, and reclaimed asphalt pavement (RAP). Mixed C&D originates largely from building construction, renovation and demolition, and is typically managed either by landfilling or processing at a mixed C&D recycling facility. As used herein, bulk aggregate primarily refers to portland cement concrete (and to a lesser extent asphalt concrete, brick and other aggregates); as generated these materials are relatively free of other components and are managed at crushing plants and or disposed as bulk fill material. RAP results from milling road surfaces as part of repaving projects, and this material is closely tracked by the National Asphalt Pavement Association (NAPA).

Specific details regarding the C&D generation estimate are presented in Appendix A and the results are presented in Table 1. The estimate includes the three sources, as well as eight material categories. A total of 476 million tons of C&D was estimated. The greatest C&D source is the bulk aggregate C&D at over 300 million tons. This material primarily consists of concrete from building demolition, and construction and demolition of other structures such as roads and bridges; the reader is cautioned that the bulk aggregate represents the C&D source with the least reliable data. The initial estimate of mixed C&D debris resulted in approximately 80 million tons. When C&D generation data for eight states were extrapolated (using population) to the entire US, approximately 120 million tons of C&D were estimated as disposed or recycled. As the state-reported C&D data were believed to largely represent mixed C&D, the 120 million tons was also considered a valid estimate. A final estimate of 100 million tons was thus assigned for the mixed C&D stream. The RAP statistics by NAPA are considered a strong estimate, accounting for over 70 million tons.

[1] The range in estimates result from the range of material/product lifespans that were considered in the estimate.

Table 1. Annual C&D generation in the US in the 2012–13 period

Material	Mixed C&D (million tons)	Bulk Aggregate (million tons)	RAP (million tons)	Total (million tons)
Aggregate	29.9	298.3	—	328.2
Asphalt Concrete	—	7.3	71.0	78.2
Wood	29.9	—	—	29.9
Drywall	6.3	—	—	6.3
Asphalt Shingles	7.9	—	—	7.9
Steel and other metal	2.6	—	—	2.6
Fines	23.0	—	—	23.0
Cardboard	0.4	—	—	0.4
Total	100.0	305.5	71.0	476.5

2.2 C&D Recycling

For each C&D category, the recycled fraction of the C&D generated was estimated. For mixed C&D, recycling rates were determined from available state reported data from eight states (Florida, Maine, Maryland, Massachusetts, South Carolina, Texas, Virginia, Washington). These states represented those that reported statewide disposed C&D and recycled C&D (see Appendix B). Based on these data, a recycling rate of 35% for mixed C&D was selected. It was assumed that aggregate, wood, steel and cardboard would be targeted at all C&D facilities for recycling, but only a fraction of facilities would target drywall (10%), asphalt shingles (20%), and C&D fines (50%); individual material recycling rates were thus adjusted to produce an resulting overall recycling rate of 35%. For bulk aggregate, recycling rates were estimated from correspondence with professionals in the recycled aggregate crushing industry. This fraction was placed at 85%. For RAP, NAPA provides data supporting a recycling rate of over 99% (92% in new asphalt and 8.7% as aggregate).

The C&D generation estimates in Table 1 and the recycling rates for each C&D category were used to estimate the total amount of CCD recycled in the US; these results are presented in Table 2. The overall recycling rate for C&D was estimated to be 73.5% (35% for mixed C&D, 85% for bulk aggregate, and 99+% for RAP).

Table 2. Annual C&D Recycled Amounts in the US in the 2012–13 period

Material	Mixed C&D (million tons)	Bulk Aggregate (million tons)	RAP (million tons)	Total (million tons)
Aggregate	13.7	238.6	—	252.3
Asphalt Pavement	—	5.8	70.8	76.6
Wood	13.7	—	—	13.7
Drywall	0.3	—	—	0.3
Asphalt Shingles	0.7	—	—	0.7
Steel and other metal	1.2	—	—	1.2
Fines	5.3	—	—	5.3
Cardboard	0.2	—	—	0.2
Total	35.0	244.4	70.8	350.3

3.0 Environmental Benefits of C&D Recycling

The environmental benefits examined in this study included conservation of landfill space, energy conservation, and reductions in greenhouse gas emissions. Each of these benefits is examined in the following sections.

3.1 Conservation of Landfill Space

C&D recycling results in an avoidance of landfill space. Using the recycled material estimates in Table 2, the landfill area avoided was estimated (in acres associated with a 50-ft depth of debris). The bulk densities of the landfilled materials were assumed to be 1,200 pounds per cubic yard (pcy), 2,200 pcy, and 2,000 pcy for mixed C&D, bulk aggregate, and RAP, respectively. The results are presented in Table 3; over 4,300 acres of landfill area are avoided on a yearly basis.

Table 3. Annual Landfill Area Avoided through US C&D Recycling (assuming 50 ft. depth of waste)

C&D Category	Annual Landfill Area Avoided (Acres)
Mixed C&D	724
Bulk Aggregate	2,755
RAP	878
Total	4,356

3.2 Greenhouse Gas Emissions

Since the use of recycled materials in a product or process often requires less net energy compared to the use of virgin materials, recycling has the potential to result in an overall reduction in net energy use and the resulting greenhouse gas (GHG) emissions associated with this energy use. In addition, when recovered C&D materials are used as a fuel source (e.g., combustion wood), the use of fossil fuels may be offset. In this section and the next, the C&D diversion estimates provided in the previous section are used along with appropriate energy and GHG emission factors to estimate resulting benefits from recycling.

The emission factors utilized were those from the US EPA Waste Reduction Model (WARM). WARM quantifies the greenhouse gas emission and energy impacts of alternative waste management practices by calculating the product of a material's mass and the management practice's emission factor for a respective material. The emission factors were developed by the EPA and were derived from a materials life-cycle approach. WARM includes emission factors for several C&D components, including PCC, asphalt concrete, wood, drywall, asphalt shingles, brick, and steel.

The recycled quantities presented in Section 2 were multiplied by the appropriate emission factors from WARM to estimate the annual net metric tons of carbon dioxide equivalents (MTCO2E) avoided by recycling. The results of this analysis are presented in Table 4. The emission factors were acquired from the most recent WARM spreadsheet provided on the US EPA website (downloaded Dec 3, 2014). The net difference in GHG emission factors between landfilling and recycling was used for all materials except wood. For wood, the net difference between landfilling and combustion was used for the emission factor (since the primary market for recycled wood is fuel product).

Table 4. GHG Emission Savings Resulting from Annual US C&D Recycling

Material	Million Tons Diverted	Emission Factor (MTCO2E/ton)	Total MTCO2E Avoided
Aggregate	252.3	0.05	12,610,000
Asphalt Pavement	76.6	0.012	9,194,000
Wood	13.7	-0.4	-5,476,000
Drywall	0.3	-0.07	-20,000
Asphalt Shingles	0.7	0.13	94,000
Steel and other metal	1.2	4.42	5,255,000
Fines	5.3	—	—
Cardboard	0.2	3.64	639,000
Total	350.3		22,300,000

The results of this analysis found that over 22 million MTCO2E were offset by C&D recycling over the year (relative to landfilling), a magnitude that corresponds to 4.7 million passenger cars removed from the road for the entire year. Current WARM GHG emission factors for two materials (wood and drywall) assign greater GHG emissions for recycling (or combustion in the case of wood) compared to landfilling. The reason that the combustion of wood for energy results in an estimated increase in GHG emissions compared to landfilling is because the WARM emission factor (for dimensional lumber) was developed based on the assumption that much of the wood disposed in the landfill would not decay (and thus not release GHG as carbon dioxide or methane). Even though the burning of wood for fuel offsets GHG emissions from burning fossil fuel, this amount is less than the assumed carbon sequestration from wood remaining in the landfill and never decomposing. If a GHG emission factor were used where landfilled wood carbon sequestration was not counted upon, the revised analysis would result in a GHG avoidance of 9,446,000 MTCO2E (compared with -5,476,000 MTCO2E); the total GHG emissions avoidance from annual C&D recycling would in turn be estimated at 37 million MTCO2E (compared with 22.3 million MTCO2E).

3.3 Energy Savings

In a similar fashion as the GHG estimate, the recycled quantities presented in Section 2 were multiplied by the appropriate energy factors from WARM to estimate the annual energy savings (million BTU) resulting from recycling (the recycling market for wood was as fuel product). The results of this analysis are presented in Table 5. To provide perspective, the barrels of oil corresponding to the energy savings are presented as well.

Table 5. Energy Savings Resulting from Annual US C&D Recycling

Material	Million Tons Diverted	Energy Factor (Million BTU saved per ton recycled)	Energy Savings (million BTU)	Energy Savings (equivalent barrels of oil)
Aggregate	252.3	0.64	161,500,000	27,840,000
Asphalt Pavement	76.6	1.75	134,100,000	23,120,000
Wood	13.7	8.52	116,600,000	20,110,000
Drywall	0.3	3.18	922,000	159,000
Asphalt Shingles	0.7	2.99	2,169,000	374,000
Steel and other metal	1.2	67.17	79,860,000	13,770,000
Fines	5.3	—	—	—
Cardboard	0.2	15.26	2,678,000	462,000
Total	350.3		497,800,000	85,800,000

4.0 Economic Benefits of C&D Recycling

The economic benefits associated with C&D recycling were assessed using survey data and economic multipliers from the literature. Specific survey details are provided in Appendix C.

4.1 Job Creation

The recovery of valuable materials through recycling requires more employees compared to landfill disposal. One objective of the survey was to gather information on the number of jobs associated with C&D recycling. Table 6 provides the resulting jobs per million tons of C&D recycled on an annual basis for both mixed C&D recycling facilities and bulk aggregate facilities. The C&D recycling industry supports approximately 19,000 direct jobs. The number of jobs provided through landfilling was not evaluated.

Table 6. Job Creation from C&D Recycling

Facility	Tons Recycled	Job per Million Tons of Annual C&D Recycled	Estimated Jobs in the US C&D Recycling Facilities
Mixed C&D Recycling Facility	35,026,000	233	8,150
Bulk Aggregate Recycling Facility	244,427,000	45	11,120
Total	279,453,000	—	19,270

4.2 Economic Benefits

The economic benefits provided to local communities as a result of C&D recycling operations were assessed using results of the survey. One set of survey questions focused on the financial investment that facility owners made in the development of their facility, including components of property acquisition, site improvements, and capital equipment expenditures. These three investment categories were summed and normalized to the total amount of debris processed to develop a scaling factor that could be used to estimate the total financial investment associated with the facility capacity necessary to process the total amount of C&D recycled in a year. Separate estimates were made for mixed C&D facilities and bulk aggregate facilities. The results are presented in Table 7. Total facility investment was estimate at over $4.5 billion.

Table 7. Total Financial Investment in Existing C&D Facility Infrastructure

Facility	Million Tons Recycled	Initial Facility Investment per Million Tons of Annual C&D Recycled ($ million)	Estimated Total Initial Facility Investment for US C&D Recycling Facilities ($ million)
Mixed C&D Recycling Facility	35.0	$54.5	$1,910
Bulk Aggregate Recycling Facility	244.4	$10.9	$2,668
Total	279.4	—	$4,578

A second set of survey questions targeted C&D recycling facility output in terms of revenue. For both mixed C&D facilities and bulk aggregate facilities, the total revenue was aggregated and normalized to the amount of debris processed to develop a scaling factor that could be used to estimate the total direct economic output of US C&D recycling facilities. These results are presented in Table 8. In addition, economic multipliers were applied to the output (revenue) to account for indirect and induced effects of C&D recycling on the economy. The multipliers were selected from the National Recycling Coalition's "US Recycling Economic Information Study" by R. W. Beck; no specific mixed C&D or bulk aggregate industry multiplier was provided in this study, so the general multipliers for "recycling and reuse" were applied. "Indirect output" refers to the value of additional economic demands that C&D recycling facilities place on supplying industries. Induced output results when workers associated with the direct and indirect industries spend earnings on goods and services in the area. The direct revenue estimate places the C&D recycling industry at a more than $7 billion dollar industry, with a greater economic contribution of more than $17 billion.

Table 8. Estimated Economic Output of C&D Recycling Industry

Facility	Million Tons Recycled	Revenue per Million Tons of Annual C&D Recycled ($ million)	Direct Output ($ million)	Type I Multiplier	Direct and Indirect Output ($ million)	Type II Multiplier	Direct, Indirect and Induced Output ($ million)
Mixed C&D Recycling Facility	35.0	$54.5	$1,893	1.7	$3,218	2.36	$4,468
Bulk Aggregate Recycling Facility	244.4	$22.4	$5,475	1.7	$9,308	2.36	$12,921
Total	279.4	—	$7,368	—	$12,526	—	$17,389

5.0 Concluding Remarks

This report provides an estimate of several different benefits of the C&D recycling industry in the US. As C&D generation, disposal and recycling have not historically been well documented, the methods used for estimating benefits relied on a number of assumptions (C&D amount, composition, and disposition). Notably, that amount of bulk aggregate (concrete processed by mobile and fixed crushing plants) generated is the largest category, yet it is also the one with the least data. In the future as C&D data are more rigorously tracked and as forecasting methods are refined, generation and benefit projections will change. Regardless, the results of this analysis provide strong evidence of the economic, social and environmental benefits associated with the C&D recycling industry.

6.0 References

Beck Inc. (2001). "US Recycling Economic Information Study." Prepared for the National Recycling Coalition, Washington, D.C., USA.

Cochran, K., Townsend, T. (2010) "Estimating Construction and Demolition Debris Generation Using a Materials Flow Analysis Approach." Waste Management, 30: 2247-2254.

Franklin Associates (1998). Characterization of Building-Related Construction and Demolition Debris in the United States. EPA530-R-98-010. US Environmental Protection Agency, Washington, D.C., USA.

US Environmental Protection Agency (USEPA), 2009. Estimating 2003 Building-Related Construction and Demolition Materials Amounts. EPA530-R-09-002. Washington, D.C., USA.

Appendix A. C&D Generation Methodology

The methodology for estimating C&D generation in 2012 is as follows:

Basic Approach

The amount of C&D generated is determined as the sum of the three different source categories: mixed C&D, bulk aggregate, and reclaimed asphalt pavement (RAP), such that:

$$CD_T = CD_{MX} + CD_{BA} + CD_{RAP}$$

Where CD_T = the total mass of C&D, CD_{MX} = the mass of C&D produced as a mixed C&D source (primarily building related), CD_{BA} = the mass of C&D produced as a bulk aggregate source (primarily concrete from large structure demolition and road and bridge work), and CD_{RAP} = the mass of C&D produced as RAP (milled pavement by paving contractors).

Determination of CD_{MX}

As CD_{MX} originates primarily from building debris, the Cochran and Townsend MFA analysis for building debris was used as a starting point. This analysis was conducted for 2002 and resulted in an estimated 198 million tons of building-related C&D (based on a typical materials lifespan). This compares relatively well to the EPA's 2003 estimate of 170 million tons of building-related C&D so it was considered a reasonable estimate. Thus, for this analysis, $CD_{BD,2002}$ = 170 million tons.

The mass of building-related C&D for 2012 was then estimated by scaling the 2002 estimate. Several scaling factors were evaluated, but new housing permits was selected. In a separate evaluation of C&D generation methodologies that the author has been associated with, housing permit values were found to provide a good scaling factor to account for the impact of economic conditions on C&D generation at the state level based on reported data. The ratio of new housing permits in 2012 to 2002 is 0.475 (it was greater in 2002). This factor was thus applied as follows:

$$CD_{BC,2012} = CD_{BC,2002}\ (0.475)$$

This resulted in an estimate of building-related C&D as follows:

Material	Building Construction (million tons)	Building Demolition (million tons)	
Concrete	5.03	43.89	
Brick / Clay Tiles	0.31	9.09	
Wood	2.38	21.68	
Drywall	1.54	3.55	
Asphalt Shingles	0.78	5.59	
Steel	0.00	2.09	
Total	10.05	85.90	***95.95***

Since some of the building debris also included bulk aggregate that would not go to a mixed C&D facility, but would go instead to a bulk aggregate facility, a fraction of the aggregate from the building debris estimate was removed and instead designated to be a part of CD_{BA} (see next section). The survey data were used to estimate an approximate ratio of wood to aggregate at mixed C&D facilities. An approximate ratio of 1 part wood to 1 part aggregate (by mass; much larger for volume) was determined.

This was then used to estimate the building debris composition with an appropriate amount of aggregate removed. This is presented in the following table, where both construction and demolition debris have been combined and concrete and brick/clay tiles have been combined as aggregate.

Material	C&D (million tons)
Aggregate	24.07
Wood	24.07
Drywall	5.09
Asphalt Shingles	6.37
Steel	2.09
Total	61.69

Since the MFA analysis does not estimate some components that are known to be in mixed C&D, the survey data were used to determine the relative amount of C&D fines and cardboard associated with mixed C&D. Thus the final mixed C&D estimate was:

Material	C&D (million tons)
Aggregate	24.07
Wood	24.07
Drywall	5.09
Asphalt Shingles	6.37
Steel	2.09
Fines	18.51
Cardboard	0.31
Total	80.51

CD_{MX} = 80.5 million tons

When C&D generation data for eight states were extrapolated (using population) to the entire US, approximately 120 million tons of C&D were estimated as disposed or recycled. As the state-reported C&D data were believed to largely represent mixed C&D, the 120 million tons was also considered a valid estimate. A final estimate of 100 million tons was thus set for the mixed C&D stream. This was scaled to the composition presented above.

Determination of $C\&D_{BA}$

The bulk aggregate C&D estimate consisted of three primary components, expressed as follows:

$$CD_{BA} = CD_{BA,building} + CD_{BA,RB} + CD_{BA,Other}$$

Where $CD_{BA,building}$ = the mass of CD_{BA} coming from buildings, $CD_{BA,RB}$ = the mass of CD_{BA} coming from roads and bridges, and $CD_{BA,other}$ = the mass of CD_{BA} coming from other structures. The $CD_{BA,building}$ estimate was determined in the mixed C&D step (the aggregate removed from the mixed C&D building debris estimate). The estimates for $CD_{BA,RB}$ and $CD_{BA,other}$ were derived from the 2002 Cochran and Townsend MFA estimated and adjusted to 2012 using a scaling factor to account for different debris generation activity. The scaling factor used for the mixed C&D (0.475) was not used as this was based on residential building permits. A variety of other scaling factors were evaluated. Scaling factors based on total nonresidential construction spending and total highway and street construction spending from the US

Census Bureau (adjusted for inflation) were 1.01 and 1.1, respectively, thus a scaling factor of 1 was used for the bulk aggregate debris estimate.

Source	Million tons
Aggregate from building MFA (not going to mixed C&D)	34.26
PCC from road and bridge estimate	132.0
PCC from other estimate	132.0
Total	298.3

This estimate was then adjusted to account for a small fraction of asphalt that ends up at bulk aggregate facilities that is later recycled as RAP. This amount was estimate at 2.5%.

Source	PCC	Asphalt	
Aggregate from building MFA (not going to mixed C&D)	34.26	0.84	
PCC from road and bridge estimate	132.0	3.22	
PCC from other estimate	132.0	3.22	
Total	298.26	7.27	305.53

CD_{BA} = 305.5 million tons

Determination of CD_{RAP}

The amount of RAP generated was not taken from the Cochran and Townsend MFA assessment, but instead data from the National Asphalt Pavement Association was used.

CD_{RAP} = 70.95 million tons

Determination of CD_T

The total amount of C&D produced in 2012 was estimated as the sum of CD_{MX}, CD_{BA} and CD_{RAP}.

CD_T = 476.5 million tons

Appendix B. State-Reported C&D Data

State	Reported C&D Disposal (tons)	Reported C&D Recycled (tons)	Reported C&D Total (tons)	% Recycled
Florida	4,422,861	3,097,791	7,520,652	42.2%
Maine	329,562	54,960	384,522	14.3%
Maryland	1,452,670	196,164	1,648,834	11.9%
Massachusetts	440,000	2,250,000	2,690,000	86.6%
South Carolina	2,894,242	690,826	3,585,068	19.3%
Texas	4,972,998	408,256	5,381,254	7.6%
Virginia	3,476,690	309,996	3,786,686	8.2%
Washington	2,115,982	3,655,698	5,771,680	63.3%
Total	20,105,005	10,633,691	30,768,696	34.5%

Appendix C. Facility Survey

1. ***Recycling Operations:*** **Please identify the types of C&D recycling operations employed at your facility: (Select all that apply.)**

   - ☐ Single facility operated by a single company
   - ☐ Multiple facilities operated by a single company (Number of facilities: ___)
   - ☐ Mechanized Material Recovery (Mixed C&D Positive Sorting)
   - ☐ Manual Separation (Mixed C&D)
   - ☐ Crushing Operation (Concrete, Asphalt, Brick Block)
   - ☐ Processing Contaminated Soils
   - ☐ Green Waste Processing
   - ☐ Other (Please Specify: _____)

2. ***2013 Material Generation:*** **What was the total amount of material accepted by your facility in 2013? If an amount is unknown, please provide an estimate. Please specify units.**

   Weight: _____ Volume: _____

3. ***Permit Capacity:*** **What is your capacity under your state or local operating permit?**

   Tons per Day: _____ Tons per Year: _____

4. ***Composition & Recycling Rate by Component:*** **Please elaborate on the percent composition of the C&DD received at your facility in 2013 for each material listed below. For each material, provide an estimate of the percent diverted, either recycled or beneficially reused. If your facility processes a material that is not listed, choose "Other" and provide a description. Please respond in the format: % of Total C&DD Received, % of Material Recycled/Recycled.**

Concrete: ____ ____	Paper: ____ ____	Cardboard: ____ ____
Asphalt: ____ ____	Glass: ____ ____	Green Waste: ____ ____
Bricks & Masonry: ____ ____	Metal: ____ ____	Carpet/Padding: ____ ____
Drywall/Gypsum : ____ ____	Plastic: ____ ____	Other: ____ ____

   Fuel Product (Wood, shingles, etc.): _____ Fines (recovered screened material) : _____

5. ***End Market Category:*** **Please elaborate on the percent of your facility's reclaimed materials that is used by the following end market category. If your facility processes a material that is used by another end market, choose "Other" and provide a description.**

Land Application ____	Landfill Cover ____
Remanufacturers ____	Road Base Construction ____
Beneficial Use ____	Other Construction Applications ____
Fuel ____	Other: _____

6. ***Employment:*** **Please quantify the following regarding employment at your facility.**

   Number of employees: _____ Total man-hours worked per week: _____

7. ***Facility Consumption & Acreage:*** **How much of the following does your facility consume annually?**

   Electricity (kWh) _____ Diesel (gallons) _____
   Natural gas (therms) _____ What is your total facility area (acres)? ____

8. ***Facility Equipment:*** **Please provide the quantity of each type of equipment used at your site and indicate other collection equipment and containers.**

   Mechanized Sorting Lines: ____ Crushers: ____
   Manual Sorting Lines: ____ Screeners: ____
   Front End Loaders: ____ Roll-Offs: ____
   Transfer Trailers: ____ Other: ____

9. ***Financial Investment:*** **Please estimate the amount of investment in the following categories:**
   Property Acquisition ($): _____ Improvements ($):_____ Equipment ($):_____

10. ***Economic Benefit:*** **We are trying to quantify your economic benefit to the community. Please provide the following:**

    Host Community Benefits: ____ Annual revenue ($):_____
    Charitable Contributions: _____ Annual Taxes Paid ($):_____
    In-Kind Services – Please Specify: ____

11. ***Market Value:*** **Please provide an estimate of the market value ($ per ton) of each C&DD material at your facility. This information will solely be used to quantify economic benefits of recycling the material and will <u>not</u> be publicly disclosed.**

    Concrete: ___ Paper: ___ Cardboard: ___
    Asphalt: ___ Glass: ___ Green Waste: ___
    Bricks & Masonry: ___ Metal: ___ Carpet/Padding: ___
    Drywall/Gypsum: ___ Plastic: ___ Other: ___
    Fuel product (Wood, shingles, etc.): ___ Fines (recovered screen material) : ___

12. **Thank you for taking the time to complete this survey. Please provide any additional information about your operations that you believe would be important in our interpretation of your answers. If you are willing to be contacted about your survey answers for the purpose of this research, please provide the name of your company along with contact information.**

Appendix D. Summary of Facility Survey Results

Question 1: Recycling Operations
Number of Responding Facilities: 69

Operation	Responses [1]	Operation	Responses
Single facility operated by a single company operated by a single company	40	**Crushing Operation (Concrete, Asphalt, Brick Block)**	26
Multiple facilities operated by a single company	21	**Processing Contaminated Soils**	7
Mechanized Material Recovery (Mixed C&D Positive Sorting)	29	**Green Waste Processing**	15
Manual Separation (Mixed C&D)	32	**Other** [2]	6

[1] Some facilities selected multiple operations.
[2] Other includes: baling, grinding, shredding, metal recycling

Question 2: 2013 Material Generation
Number of Responding Facilities: 48

Responses[2]	Generation	Minimum	Average	Maximum
47	*Weight (tons)*	10,000	3,310,000	149,000,000
7	*Volume (yd^3)*	12,000	290,000	751,000

[2] Some facilities reported values for both weight and volume.

Question 3: Permit Capacity
Number of Responding Facilities: 49

Responses	"No Limit"	Capacity	Minimum	Average	Maximum
44	15	*Tons per day*	100	2,210	20,400
29	11	*Tons per year*	5,000	305,000	1,320,000

Question 4: Composition & Recycling Rate by Component

	Composition by Component Responses: 23 [3]			Recycling Rate by Component Responses: 22			
Material	*Minimum*	*Average*	*Maximum*	*Recycling Responses*	*Minimum*	*Average*	*Maximum*
Concrete	0%	27%	98%	17	11%	95%	100%
Asphalt	0%	3.7%	35%	10	5%	79%	100%
Bricks & Masonry	0%	3.1%	20%	8	13%	89%	100%
Drywall/ Gypsum	0%	3.0%	15%	4	100%	100%	100%
Paper	0%	0.7%	12%	3	0%	33%	100%
Glass	0%	0.7%	10%	4	0%	50%	100%
Metal	0%	5.4%	30%	11	80%	98%	100%
Plastic	0%	1.3%	5.0%	8	0%	50%	100%
Cardboard	0%	3.1%	15%	6	0%	83%	100%
Green Waste	0%	2.4%	30%	8	80%	98%	100%
Carpet/ Padding	0%	0.5%	5.0%	5	0%	20%	100%
Fines	0%	8%	60%	6	20%	87%	100%
Fuel Product	0%	35%	100%	10	24%	91%	100%
Other	0%	5.1%	47%	10	0%	81%	100%

[3] Excludes facility responses whose composition does not sum to 100%

Question 5: End Market Category
Number of Responding Facilities: 18 [4]

End Market	Minimum	Average	Maximum
Land Application	0%	3.1%	30%
Remanufacturers	0%	9%	60%
Beneficial Use	0%	14%	65%
Fuel	0%	12%	90%
Landfill Cover	0%	8.1%	60%
Road Base Construction	0%	42%	100%
Other Construction Applications	0%	8.2%	45%
Other	0%	3.9%	30%

[4] Excludes facilities whose end market percentage does not sum to 100%

Question 6: Employment
Number of Responding Facilities: 46

Responses	Employment	Minimum	Average	Maximum
46	*Number of Employees*	2	32	248
45	*Total man-hours worked per week*	40	1,160	9900

Question 7: Facility Consumption & Acreage
Number of Responding Facilities: 45

Responses	Consumption	Minimum [5]	Average	Maximum
22	*Electricity (kWh)*	110	303,000	1,420,000
36	*Diesel (gallons)*	1,200	63,500	400,000
5	*Natural gas (therms)*	1	12,500	25,600
41	*Total facility area (acres)*	1	31	220

[5] Minimum when consumption is greater than zero.

Question 8: Facility Equipment
Number of Responding Facilities: 47

Responses	Equipment Type	Minimum [6]	Average	Maximum
21	*Mechanized Sorting Lines*	1	1.1	2
31	*Manual Sorting Lines*	1	1.3	4
44	*Front End Loaders*	1	3.4	22
22	*Transfer Trailers*	1	6.4	38
23	*Crushers*	1	2.1	7
37	*Screeners*	1	2.3	14
38	*Roll-offs*	1	40	370

[6] Minimum when consumption is greater than zero.

Question 9: Financial Investment
Number of Responding Facilities: 34

Responses	Investment	Minimum	Average	Maximum
32	*Property Acquisition ($)*	$50,000	$1,440,000	$10,000,000
32	*Improvements ($)*	$20,000	$2,000,000	$20,000,000
34	*Equipment ($)*	$150,000	$3,330,000	$40,000,000

Question 10: Economic Benefit
Number of Responding Facilities: 37

Responses	Economic Benefit	Minimum	Average	Maximum
35	*Annual Revenue ($)*	$200,000	$6,420,000	$60,000,000
25	*Annual Taxes Paid ($)*	$3,500	$1,090,000	$24,000,000
10	*Host Community Benefits* [7]	$3,000	$124,000	$1,000,000
18	*Charitable Contributions* [7]	$300	$75,500	$1,000,000
7	*In-Kind Services* [7]	$2,500	$25,300	$50,000

[7] Qualitative information not included.

Question 11: Market Value
Number of Responding Facilities: 35

Responses	Material	Minimum	Average	Maximum
31	*Concrete*	$0	$7.10	$21.60
24	*Asphalt*	$0	$7.50	$30.00
15	*Bricks & Masonry*	$0	$5.90	$50.00
13	*Drywall/Gypsum*	$0	$6.50	$29.00
10	*Paper*	$0	$60.80	$140.00
10	*Glass*	$0	$13.20	$87.60
24	*Metal*	$0	$295.00	$2,500.00
15	*Plastic*	$0	$106.00	$350.00
19	*Cardboard*	$15.00	$80.30	$135.00
8	*Green Waste*	$0	$7.80	$25.00
10	*Carpet/Padding*	$0	$64.70	$225.00
10	*Fines*	$0	$3.20	$21.40
18	*Fuel Product*	$0	$24.40	$85.00