CONSTRUCTION AND DEBRIS (C&D) RECYCLING ROADMAP

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EXECUTIVE SUMMARY

The Construction and Demolition Recycling Association (CDRA) contracted the University of Florida to create a recycling roadmap for state and local governments on managing construction and demolition debris (C&D). Included in this document is a description of C&D characteristics including, sources of C&D generation, different types of processing strategies used in recycling facilities, the benefits of recycling C&D material, and suggestions for municipalities on developing recycling markets for C&D.

The C&D waste stream consists of seven common materials: portland cement concrete (PCC), asphalt pavement, wood, asphalt shingles, gypsum drywall, metals, and fines. Other materials, such as packaging materials, plastics, carpet, and ceiling tiles are also present in C&D, but in lower quantities and frequency. C&D is generated from four main sources: construction, demolition, renovation, and roads, bridges, and other infrastructure projects. The material composition and quantity varies among project types. C&D collected from these sources are may be either source separated or comingled and often sent to a recycling facility for material recovery. Recycling facilities utilize both manual and mechanical features to process incoming C&D. Facilities employ different processing strategies, such as dump and pick, single line, or dual line sorting. Recycling C&D material has a multitude of economic, environmental, and social benefits. As opposed to landfilling C&D, recycling C&D in 2014 resulted in 43.9 Million $MTCO_2E$ avoided and the creation of 27.9 thousand jobs.

Municipalities play a crucial role in supporting the growth of C&D recycling markets, financially and legislatively. Local governments can develop financial support programs to promote recycling facilities purchase advanced processing equipment, cover fees associated with permitting a new recycling facility or incentivize projects to use recycled materials instead of virgin materials. Legislative and regulatory opportunities include establishing ordinances that require haulers to drop materials off at certified recycling facilities prior to disposal, creating procurement policies that provide end markets, instituting disposal bans for certain C&D materials, and requiring minimum diversion targets for construction and demolition projects.

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ABBREVIATIONS AND ACRONYMS

C&D	Construction and demolition debris
EPA	U.S. Environmental Protection Agency
GHG	Greenhouse gas
MRF	Material recovery facility
MSW	Municipal solid waste
SMM	Sustainable materials management

UNITS OF MEASURE

mmBTU	Million British thermal units
t	Metric tonnes = 1.1 tons
tCO_2eq	Tonnes carbon dioxide equivalence
tons	US short tons = 2,000 pounds

1 INTRODUCTION

1.1 Definition and Description of C&D

Construction and demolition debris (C&D) is a category of the solid waste stream. The US EPA does not include C&D in municipal solid waste (MSW). C&D includes materials generated from road and infrastructure projects as well as from the construction, demolition, and renovation of buildings. The materials are generated in varying amounts based on factors such as project type, project size, age of structure, condition of structure, and geographic location. Broadly, the C&D stream is comprised of concrete, wood, metal, asphalt pavement, gypsum drywall, land-clearing debris, and a variety of other minor constituents. C&D debris is either source separated at the generation site or kept as a mixed C&D load. The separated or mixed C&D can then be processed at a materials recovery facilities (MRF) to be marketed for reuse. The C&D materials salvaged can be recycled into new construction products, such asphalt shingles incorporated into new asphalt for roadways. The market for C&D materials varies depending on contamination level of the debris load, quantity available, the consistency of material available, cost of processing versus disposal (i.e. landfill compared to MRF tipping fees), and location of processors.

1.2 CDRA

In the US, C&D materials are used as substitutes for virgin materials in construction projects, ingredients for new product manufacture, and fuels for energy production. Many of these materials are recycled at C&D recycling facilities to then be utilized in these new projects. The Construction & Demolition Recycling Association (CDRA), a non-profit trade association, represents the diverse group of member facilities, companies, and agencies that work within the various C&D material recycling disciplines.

While promoting and defending the environmental and economic benefits of recycling C&D materials, the CDRA has accomplished numerous legislative actions across the United States (US) and other countries. Many states across the US have felt the advantageous achievements of the CDRA, which include challenging bans that prevent C&D wood as a fuel product and increasing acceptance of products made with recycled elements. Additional achievements include working with organizations and associations to fund studies, produce white papers and projects, all to advance the recycling of C&D materials. The CDRA commitment to increase recycling is done through:
Providing positive support and representation to the industry and CDRA members in legislative and rule-making cases that impact the recycling business.
Acting as an advocate to promote C&D recycling and the recycling industry in every manner possible that benefits CDRA members.
Facilitating and sponsoring CDRA member interaction between membership companies and the many specialized service sectors that can potentially

benefit the members through equipment, financing, insurance and other specialized third-party resources.

1.3 The Role of C&D Recycling

Though much of C&D material is recycled for purely economic reasons, avoiding landfill disposal of materials such as concrete, wood, and gypsum drywall has benefits well beyond financial ones. Avoidance of landfilling provides a smarter use of natural resources, energy savings, and an increase in greenhouse gas emission avoidance. C&D recycling results in greater job creation and industrial activity relative to landfilling.

1.4 C&D Recycling and Sustainable Materials Management

The concept of Sustainable Materials Management (SMM) originated in a 2002 EPA publication entitled “Beyond RCRA: Waste and Materials Management in the Year 2020.” In 2009, EPA further developed the idea in “Sustainable Materials Management: The Road Ahead,” which presented a roadmap for moving toward SMM. In these and other documents, SMM is characterized as a varying set of resource-efficient actions to be taken across the entire lifecycle of a material or product — from extraction through refinement, manufacturing, assembly, distribution, use, and end-of-life management (Figure 1). In contrast to traditional conceptions of waste management, SMM seeks to establish policies that encourage the most productive uses for all resources while minimizing the impact of waste and pollutants at all stages. From the policy standpoint, SMM is meant to produce a long-term systemic solution to the problem of waste management that takes into account the interests of all public and private stakeholders. The recovery and recycling of C&D materials is a key element in all SMM programs. C&D may be recovered for direct reuse (e.g., use of recovered lumber in new construction projects) or utilized in other beneficial ways (e.g., crushed concrete used for road base).

Figure 1. Conceptual description of SMM (US EPA, 2018).

1.5 Document Purpose

The C&D recycling industry continues to grow in the US. Some components (e.g., concrete) are commonly recycled because of existing economic opportunities. Other components, especially those with low market value and require processing to separate from the rest of the C&D stream, are often challenging to recycle. Many state and local governments have demonstrated that regulations and policies can play a major role to promote C&D recycling. Municipalities or other entities interested in growing C&D recycling in their geographic area should look to these successes as examples. The purpose of this document is to provide governments, local and state, an overview of the C&D recycling system as well as showcase methods that governments have implemented to increase their C&D recycling rate. These efforts have ultimately lead to increased environmental and economic benefits.

1.6 Guide on Using this Document

The document is organized so that local government can understand the material types, generator types, C&D composition, generation, and disposition, C&D facility operations, the benefits of C&D recycling, and steps to successful implementation of C&D recycling. Section 2 describes the different material types, including portland cement concrete, asphalt pavement, wood, etc., generator types, and statistics on C&D in the US. Section 3 includes an overview of the various C&D recycling facility operations, including a “tour” of a C&D recycling facility. Section 4 contains information on the benefits of C&D

recycling, such as the environmental and economic benefits. Details on the types of markets and policies supporting C&D recycling are included in Section 5. A summary regarding prospective C&D recycling tasks local governments may institute are shown in Section 6.

2 THE UNIVERSE OF C&D

2.1 C&D Material Types

A summary of common C&D materials is presented in Table 1 and the subsections below provide more in-depth descriptions of these materials.

Table 1. Common materials present in C&D.

Material	Description
Portland Cement Concrete	Consists of a mixture of cement paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates (such as sand, gravel, or crushed stone) which then forms the mixture into a rock-like mass.
Asphalt Pavement	Also called bituminous concrete, this material is a mixture of fine and course aggregate with the asphalt serving as the binder. The asphalt present is approximately 6% by mass of the total pavement quantity.
Wood	Wood includes two categories, dimensional and engineered wood. Residential homes commonly utilize wood products as a major construction material.
Asphalt Shingles	Common roofing material used for sloped roofs containing 30-40% asphalt, by mass, and underlain by asphalt soaked felt or paper.
Gypsum Drywall	Gypsum (calcium sulfate dihydrate) drywall is a manufactured building product in the form of a panel used for interior wall and ceiling surfaces in buildings. The sheets are primarily composed of gypsum (~90%) and paper surfacing and backing.
Metal	Numerous metal construction materials are encountered in C&D. These include steel in structural supports, flashing and siding systems, and as part of plumbing and electrical utilities. Metals include ferrous and nonferrous, such as steel, aluminum, and copper.
Packaging Materials	C&D recyclers recover packaging materials such as cardboard and plastic.
Fines	In the process of separating C&D components from one another for recycling, mechanical screens are used to sift out larger from finer material. A product of this operation is C&D fines which consist of soil and small pieces of concrete, brick, wood, and other C&D materials. The defining size of these fines depends on the specific processing plant.
Other	Carpet, ceiling tiles and vinyl siding are among C&D materials, but are not produced in large quantities and consistent markets are often not established.

2.1.1 Portland Cement Concrete

Portland cement concrete (PCC) is often produced in large amounts. PCC is used for building foundations, structural components, roads, and bridges. PCC contains coarse and fine aggregate, Portland cement, and water. PCC is manufactured at concrete batch plants, where the aggregates, cement and water are mixed together to meet an engineered product design. The PCC is distributed to construction sites or concrete product manufacturing plants via mixing trucks.

2.1.2 Asphalt Pavement

Asphalt (also known as liquid asphalt, asphalt cement, or bituminous concrete) is a sticky, black, semi-solid, naturally occurring form of petroleum used to create pavement. To generate the asphalt pavement used in road construction, asphalt (approximately 5% by mass) is mixed and heated with dried coarse and fine crushed rock, which act as an aggregate. The aggregates, along with various binders and fillers, are 95% by mass. Asphalt is most commonly used to produce hot, warm, and cold mix asphalt pavement for road paving.

Asphalt pavement is typically produced in hot mix asphalt plants, which consist of drum or batch mix plants that blend aggregate, asphalt cement, and in many cases, recycled materials (predominantly Recycled Asphalt Pavement (RAP)), to meet an engineering mix design. The mix is then hauled by truck to the construction site and compacted in place.

Figure 2. Asphalt concrete (or asphalt pavement) poured onto a road.

2.1.3 Wood

Wood products are heavily used in building construction in the US, especially in residential construction, as well as for a number of outdoor structural applications (fences, decks, and utility poles). The material is generated as scrap debris during construction as well from demolishing structures. Wood is used in many parts of a building such as in the wall and roof structure, cabinets, and flooring. Wood can be classified as either dimensional lumber or engineered wood, also known as manufactured wood.

2.1.3.1 Dimensional Lumber

Dimensional lumber consists of planks of lumber made up of a singular wood type and cut to desired dimensions. Dimensional lumber is also used in round posts or poles for outdoor use. Especially for outdoor use, dimensional lumber can be treated with preservatives such as chromium copper arsenate (CCA) to prevent decaying due to the natural elements or insects. Some wood components may be salvaged for reuse prior to demolition, especially if kept clean and dry.

2.1.3.2 Engineered Wood

Engineered wood, also known as manufactured wood, comprises multiple wood types bonded together using adhesives. Pieces of various wood types can either be slurred or veneered together. This category of wood includes oriented strandboard (OSB), plywood, and fiberboard. Manufactured wood cannot be recycled like untreated, unpainted dimensional lumber. While there are limited opportunities for reuse of these products, there are no real outlets for recycling and most is used as a fuel source.

Figure 3. Shredded wood can be used for fuel, landscape mulch or to make engineered wood products.

2.1.4 Asphalt Shingles

Asphalt shingles are used on roof structures. Asphalt shingles are comprised of an asphalt impregnated mat as the base with the bottom side coated in a fine mineral surface and the top side coated with a coarser mineral fraction. The shingles are held onto the rood using nails and oriented in a shingle pattern. Often, the coarse fraction are dyed to meet a desired product appearance. The asphalt content is usually 20%-30% of the total asphalt shingle mass.

Figure 4. Asphalt shingles collected at landfill.

2.1.5 Gypsum Drywall

Gypsum drywall is used as the interior wall material in both residential and commercial buildings. Drywall consists of a gypsum core covered on each side with a paper backing. Gypsum contributes over 90% of the mass to the drywall product. During the construction process, drywall sheets are fixed to the internal framing with nails. The joints and screw locations are then covered over with a binding compound and sanded to form a smooth surface.

Figure 5. Source separated gypsum drywall sheets (Gypsum Association, 2019).

Figure 6. Gypsum separated from drywall is typically used an agricultural product

2.1.6 Metals

Metal products are encountered in a variety of building applications and in other structures. Different ferrous, non-ferrous, and alloy metals, including steel (such as galvanized steel), cast iron, aluminum, brass, tin, lead, and copper can be found in C&D loads. Products in these loads include structural beams, flashing, piping, and electrical components.

Figure 7. Steel, aluminum, brass, and copper are among the metals commonly recycled from C&D.

2.1.7 Fines

At mixed C&D processing facilities, smaller materials are screened out from larger ones as part of the separation process. C&D fines, typically on the order of 1-inch size or less, contain soil and small pieces of concrete, asphalt, wood and gypsum. The fines can replace virgin soil as landfill cover or be used as non-structural fill material.

Figure 8. A pile of C&D fines after C&D load has been processed.

2.2 Generator Types

2.2.1 Construction

C&D is generated during construction of structures, road structures, and bridges. Gypsum drywall debris mass will be higher than from demolition activities. The drywall will be generated during the interior finishing stage. Packaging materials such as plastic and cardboard are usually generated during the last stages of construction. Some of the wood debris will be generated during the site preparation and foundation construction, but most will be generated during the framing and roofing stages. It is common practice for the general contractor to provide labor to place debris in a container (e.g., roll-off box) and hire a subcontractor to haul the container to recycling or disposal facilities. Figure 9 and 10 show examples of construction debris collection using a roll-off box.

Figure 9. Building construction with a roll-off box used to collect construction debris.

Figure 10. Home construction with a roll-off box used to collect construction debris.

2.2.2 Demolition

Demolition is the breakdown of a structure and is typically conducted by hand, using mechanical equipment, or by controlled explosion. C&D debris generated during demolition activities are typically more comingled and are generated at much greater quantities than construction. By mass, concrete, bricks, and wood comprise most of the composition of demolition debris. Commercial demolition debris will have greater quantities of gypsum and steel. Usually, demolition requires a permit from a local building code agency since there can be hazardous materials involved and worker safety protocols must be followed. Some hazardous materials of concern include asbestos, lead flashings and paint, as well as mercury containing devices. In some cases, instead of demolishing a structure, deconstruction occurs. During deconstruction, components are taken apart piece by piece to optimize recovery value since source separation leads to less effort when processing the waste. However, deconstruction faces many challenges, including a lack of economic feasibility because the material is usually not worth enough on its own to be valuable unless it is donated to a nonprofit organization so a tax write off can be taken, and that much of the material generated is not good enough to reuse and will have no market value. Figures 11 and 12 present examples of demolition sites.

Figure 11. Building demolition with equipment collecting demolition debris.

Figure 12. Home demolition with equipment collecting demolition debris.

2.2.3 Renovation

Renovations occur when a structure is being fixed or additional components are added on. The resulting debris is most similar to demolition debris; however, material percentages will vary depending on the scope and size of renovation. In addition, commercial renovation projects will generate other recyclable materials not generally found in residential projects, such as acoustic ceiling tile and carpet tiles. Examples of renovation debris generated from sites are shown in Figures 13 and 14.

Figure 13. Building renovation with roll-off box used to collect debris.

Figure 14. Building renovation with roll-off box and trash chute used to collect debris.

2.2.4 Road, Bridge, and Other Infrastructure

Debris generated during road, bridge, and other infrastructure projects is typically made up of concrete, metal, and asphalt pavement. The metal is due to the rebar used in road construction. Asphalt pavement is heavily used in the US as a paving layer in roadways and parking lots. The material is typically produced in hot mix asphalt plants, hauled to the construction location, and then compacted on site. The pictures in Figures 15 and 16 depict on site recycling of asphalt pavement, which involves the removal, reconditioning, and reapplication of old pavement.

Figure 15. Reclaimed asphalt pavement collected and placed during road renovation.

Figure 16. Reclaimed asphalt pavement collected during road renovation.

2.3 C&D Composition, Generation, and Disposition

The total mass of C&D generated in the US in 2014 was 583 million tons. The composition of all C&D, generated from all four generators discussed above, resulted in concrete (65%) to be the largest material component, followed by reclaimed asphalt pavement (14%), both by mass. Figure 17 presents the mass composition of C&D for the US in 2014 and Table 2 shows the generated, landfilled, and recycled masses of each C&D material component in 2014. The overall recycling rate for C&D was 73% with concrete and RAP both reaching recycling rates higher than 80% (82% and 93%, respectively). Most of the concrete is used as aggregate for road base and most of the RAP is used in the remanufacture of new asphalt pavement.

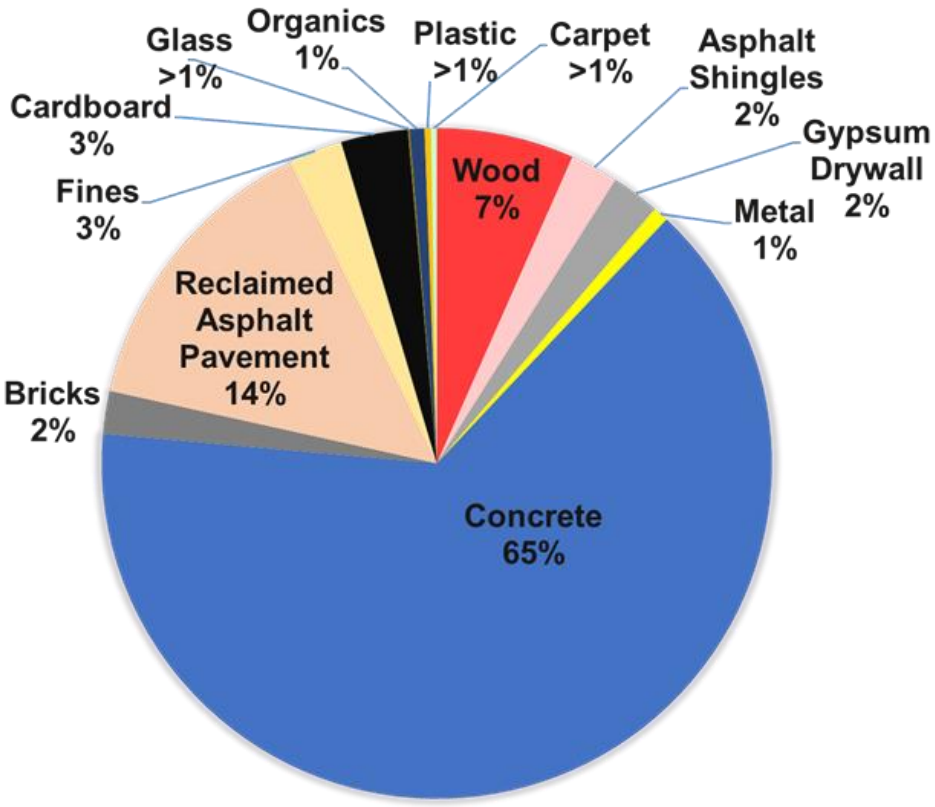


Figure 17. Estimated Composition of C&D in the US in 2014 (Townsend et al., 2017).

Table 2. C&D components and associated generated, landfilled, and recycled masses. (Townsend et al., 2017).

Component	Generated (tons)	Landfilled (tons)	Recycled (tons)		Recycled Total (tons)	Recycling Rate (%)
Wood	38,680,000	25,163,062	Fuel	9,077,273	13,516,938	35%
			Mulch	2,821,650		
			Remanufacture	1,472,763		
			Compost	145,252		
Asphalt Shingles	13,542,000	12,260,411	Fuel	25,260	1,281,589	9%
			Remanufacture	1,175,604		
			Aggregate	80,725		
Gypsum Drywall	13,590,000	9,690,926	Agricultural	3,490,272	3,899,074	29%
			Remanufacture	408,802		
Metal	4,349,000	1,865,932	Remanufacture	2,483,068	2,483,068	57%
Concrete	375,297,000	67,251,133	Aggregate- Road Base	250,895,168	308,045,867	82%
			Aggregate- Drain Rock	6,297,103		
			Aggregate- Other Construction	20,595,928		
			Remanufacture	30,257,667		
Bricks	12,041,000	10,269,294	Aggregate	1,771,706	1,771,706	15%
Reclaimed Asphalt Pavement	83,494,914	5,911,200	Remanufacture	67,823,954	77,583,714	93%
			Aggregate	9,195,398		
			Other	564,361		
Fines	15,166,669	8,509,105	Landfill Cover	5,604,496	6,657,564	44%
			Fill Material	520,018		
			Road Base	533,050		
Cardboard	18,812,876	12,903,884	Remanufacture	5,908,992	5,908,992	31%
Glass	528,094	362,223	General Recycled	165,871	165,871	31%
Organics (e.g., Land Clearing Debris)	4,098,894	1,715,093	Compost/Mulch	724,753	2,383,801	58%
			Fuel	1,659,048		
Plastic	1,768,633	1,213,118	Remanufacture	370,726	555,515	31%
			Fuel	184,789		
Carpet	1,658,373	1,137,489	Remanufacture	6,757	520,883	31%
			Landfill Cover	514,126		
Total	583,027,452	158,252,871		424,774,582	424,774,582	73%

3 C&D RECYCLING FACILITY OPERATIONS

C&D materials are often source separated at the job site when there are large amounts of C&D generated or when most of the C&D consists of one type of material (i.e., demolition projects with debris that is mostly concrete). When a site produces smaller or more diverse C&D, the debris goes to a mixed C&D processing facility, or C&D materials recovery facility (MRF), where materials are processed and separated. Most C&D facilities are considered dirty MRFs, receiving the entire waste stream and then separating out the recycled materials. Materials are separated by a combination of manual and mechanical methods.

C&D recycling facilities vary widely in how they process C&D debris. Some facilities accept specific C&D components, such as drywall or asphalt shingles, either from other C&D recyclers or directly from generators, and process these materials into new products. If the facility receives mixed loads, a variety of approaches are used to separate recyclable components, such as wood, concrete, metal, asphalt, drywall and cardboard, from the non-recyclable debris. Gypsum drywall is often removed before mechanical separation stages. Some operations use manual labor and machinery to sort through materials dumped on a tipping floor in order to remove the easy-to-recovery components. Other facilities include enclosed processing lines with manual labor, multiple conveyor belts, size reduction devices, and mechanical separation equipment. Size reduction methods can occur in the early stages of the separation process of mixed C&D to assist in sorting. Concrete processing operations accept loads of concrete, brick, block and paving materials and then employ a suite of size-reduction, screening, and magnetic separation technologies to create products ready for new construction projects. Due to the differences in C&D processing, fines generated will vary in composition and size. Three common styles used in mixed C&D recycling facilities, dump and pick, single line mechanical, and dual line mechanical are described below in Figures 18-20. A brief tour of a C&D recycling facility is provided chronologically in Figures 21-26.

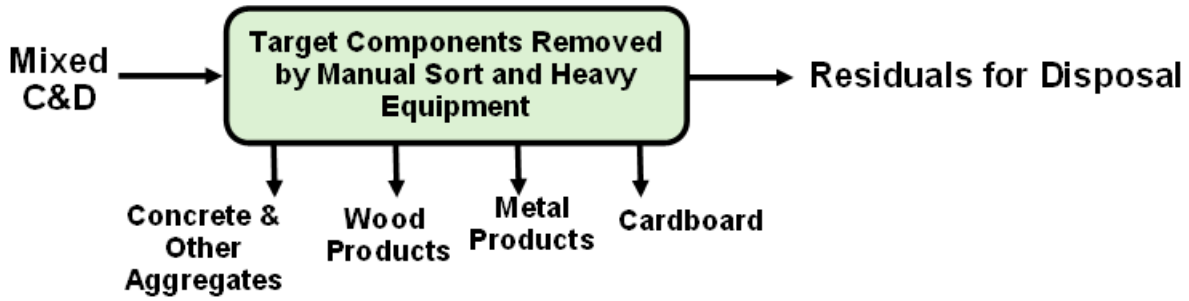


Figure 18. Dump and pick recycling facility production flow. Dump and pick facilities are the simplest because they use laborers and equipment at the tipping face of the landfill or transfer station to pick through loads of C&D and manually select the highest-value materials.

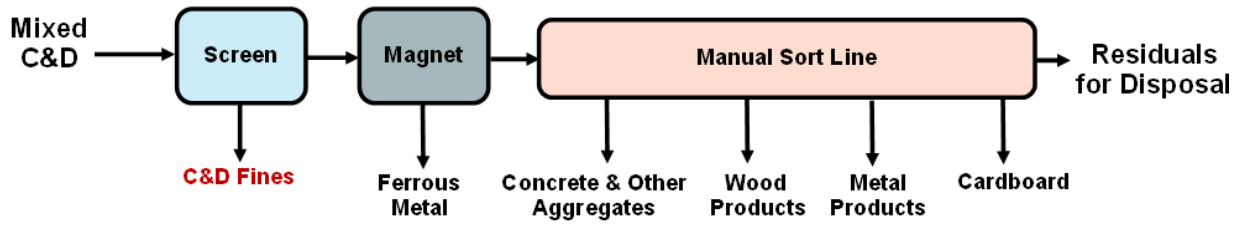


Figure 19. Single line mechanical facility production flow. Single line facilities use both manual separation and mechanical equipment to sort mixed C&D materials. A single line uses a single screen to generate one fine fraction.

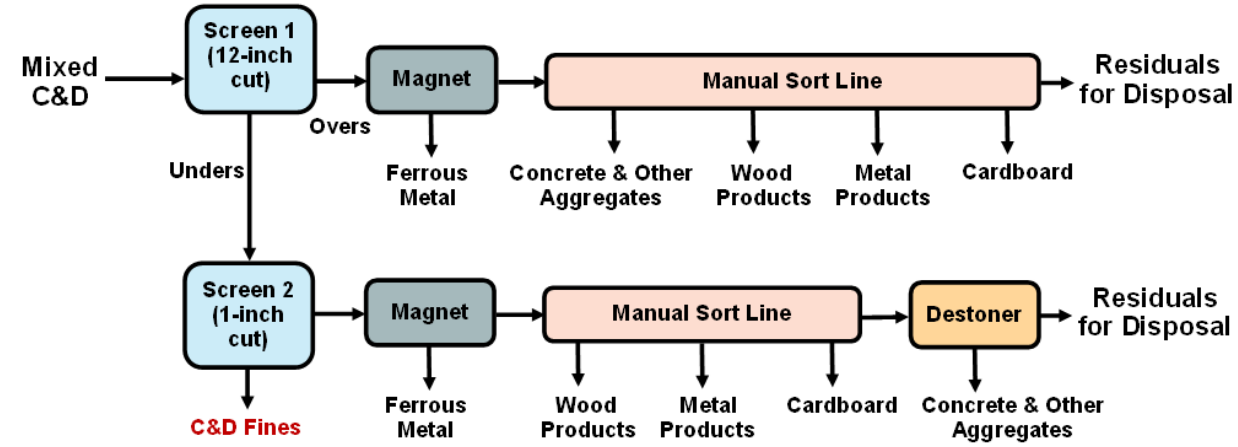


Figure 20. Dual line mechanical facility production flow. Dual line facilities use both manual separation and mechanical equipment to sort mixed C&D materials. A dual line uses two screens to generate two fine fractions.

Figure 21. Overview of dual line mechanical facility production flow.

Figure 22. Start of facility where the debris is placed on the conveyer belt to be sorted using manual and mechanical measures.

Figure 23. As the debris is carried upon the conveyer, it is placed on top of a series of screens.

Figure 24. The debris that falls through the screens is collected as recovered screened material or fines.

Figure 25. The remaining materials that do not fall through the screens in Figures 23 and 24 are manually sorted into material categories.

Figure 26. The material categories from Figure 25 are collected in separate bins for reuse or market sales.

4 THE BENEFITS OF C&D RECYCLING

4.1 Potential to Increase Recycling Rate

In 2014, the total mass of C&D generated in the US was 583 million tons, 2.26 times larger than the total mass of MSW generated (US EPA, 2018). The 2014 recycling rate for C&D was 73%, which is more than double the MSW recycling rate of 35%. Recycling C&D provides an opportunity to increase the overall recycling rate of a local government due to its heavy mass and frequent contribution to the waste stream.

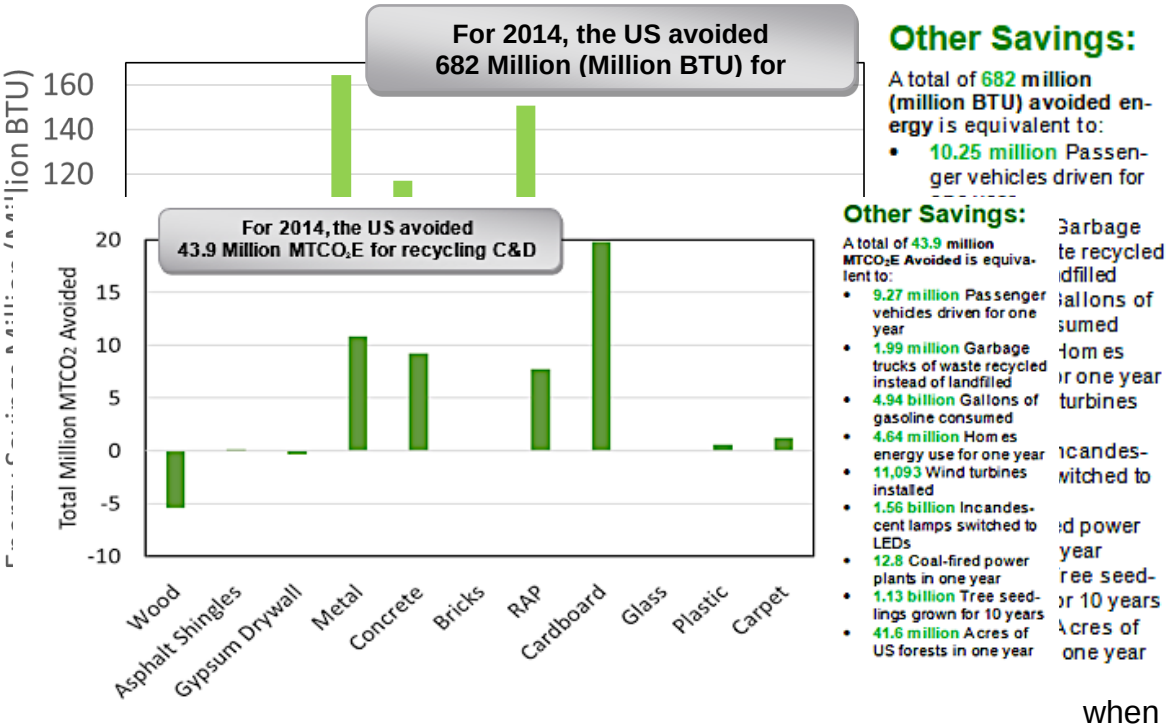
4.2 Greenhouse Gas Emissions Offsets

C&D recycling provides a source of materials that would otherwise have to be mined from the earth. Aggregate produced from crushing concrete and brick provide a substitute for virgin rock sources, recycled gypsum from drywall sheets can be used instead of naturally mined gypsum, and when metals such as steel, aluminum and copper are recovered, they offset some of the demand to extract these elements from the earth. Recycling wood and cardboard to produce fuel, mulch and new products lessens the requirement for timber harvesting or extracting fossil fuels. Diverging from virgin materials has a direct connection with decreasing greenhouse gas (GHG) emissions and saving energy. The EPA WARM (Waste Reduction Model) calculates GHG emissions and savings. Calculations in this section used the 2014 version of WARM. 43.9 million tons CO_2 Emissions ($MTCO_2E$) were avoided when selected materials were recycled as opposed to landfilled, as seen in Figure 27 As shown in the figure, recycling cardboard, metals, and concrete have relatively high potential to reduce CO_2 emissions that would otherwise be released during landfilling. According to Figure 27, wood and gypsum drywall had a negative quantity of $MTCO_2$ avoided. These negative values could be attributed to assumptions made when calculating the difference in GHG emissions between the baseline methods of landfilling to an alternative recycling method. During calculations for wood, specifically dimensional lumber, landfilling and combustion were compared. Combustion resulted in less emission avoidance than landfilling. For gypsum drywall, landfilling and recycling were compared. Recycling resulted in less CO2 emissions avoided than landfilling.

Figure 27. Avoided greenhouse gas associated with recycling instead of landfilling each material (Townsend et al., 2017).

4.3 Energy Use Offsets

Energy savings from C&D recycling stems from replacing virgin materials with recycled materials to manufacture new products. Recycling reduces the energy expended in the extraction and refining stages of raw materials as utilizing C&D debris already contains the elemental components. Some intermediate processing might need to occur for the debris material to be used in a new product, but the extraction stage can be skipped. For example, when scrap steel is recovered as part of a building demolition, the material may be utilized to manufacture new steel. Not only can some C&D materials be used as a virgin material substitute, they could also be used as fuel substitutes for making energy. Based on data from 2014, including the energy associated with landfilling, there was a total energy avoidance of 682 Million (Million BTU)



when specified materials were recycled as seen in Figure 28.

Figure 28. Energy savings associated with recycling and landfilling each material (Townsend et al., 2017).

4.4 Landfill Savings

Every ton of C&D recycled results in that quantity of material not buried in the ground through landfilling. Over time, landfills have to expand their capacity, in segments called cells. Diverting C&D material to recycling facilities instead of to landfills slows down landfill expansion.

Table 3. Millions of tons recycled of each category and the corresponding acres saved from recycling instead of landfilling. For 2014, recycling all the materials in resulted in a total of 5,534 acres of landfill saved. Values for recycled mass are from Table 2 and are not exact due to rounding (Townsend et al., 2017).

Recycled Material	Recycled Mass (Million Tons)	Acres Saved
Mixed C&D	63.4	1,310
Bulk Aggregate	290	3,277
RAP	76.3	947
Total	430	5,534

Additionally, environmental issues associated with C&D disposal are lessened. For example, one problem frequently encountered with C&D debris landfills is the production of hydrogen sulfide (H_2S) gas. H_2S gas is a foul-smelling gas that is produced when sulfur reducing bacteria react with the gypsum found in gypsum drywall sheets. The gas has demonstrated to pose a human health risk. Recycling scrap drywall from C&D projects into new drywall or agricultural amendments that regulate soil pH prevents the formation of this noxious gas. Overall, a decrease in dependence of landfills leads to lower cost expenditures as there is less land to operate and maintain.

4.5 Economic Value

C&D landfills and C&D recycling facilities both operate under a model where a tipping fee is charged to customers when disposing of their materials. Unlike landfills, C&D recycling facilities offer continued economic opportunities for the C&D debris. Landfills are the final destination for products, but recycling facilities sell some of the materials to manufacturing operations or directly to customers, spawning greater economic benefit to the local economy. The second life of these materials are valuable for other sectors of the economy, especially mills and manufacturing plants who purchase the recyclables to produce new products. The associated capital costs and revenue associated with recycling all C&D materials except for RAP are shown in Table 4.

Table 4. Estimated economic output of C&D recycling industry (Townsend et al., 2017).

Recycled Material	Capital Expenditures (Billion)	Direct Revenue (Billion)
Mixed C&D	$3.45	$3.42
Bulk Aggregate	$3.17	$6.51
Total	$6.63	$9.94

4.6 Job Creation

C&D recycling facilities utilize a combination of manual efforts and mechanical equipment during processing to sort recyclable components from

the incoming mixed loads. Employees are crucial in hand-picking out desired commodities from the mixed debris in addition to moving the incoming material onto the processing line, marketing, and transporting the recycled products off-site to their second life. More employees are needed to recycle C&D compared to burying the materials in a landfill. For 2014, recycling all the materials except for RAP in Table 5 resulted 27.9 thousand jobs.

Table 5. Millions tons recycled of each category and the corresponding jobs produced (Townsend et al., 2017).

Recycled Material	Recycled Mass (Million Tons)	Jobs per Million Tons of Annual C&D Recycled	Thousands Jobs Produced
Mixed C&D	63.4	233	14.8
Bulk Aggregate	290	45.0	13.3
Total	350	278	27.9

5 STEPS TO SUCCESSFUL IMPLEMENTATION OF C&D RECYCLING

5.1 Essential Elements of Successful C&D Recycling Programs

5.1.1 Markets

Probably the most important action to increasing recycling rates is to have end markets for the recycled products. Recycling market development requires strategic planning, program infrastructure, outreach to manufactures, and communication between local governments, haulers, and recyclers. The markets specific to each of the materials described in Section 2.1 are expounded below in Section 5.2. Many of these markets include using the material as a replacement of virgin material, part of structural foundations, or engineered fuel. Often, a material will have various markets, ranging from a lower to a higher market value, depending upon how it is recycled or reused. For example, a higher market value for scrap gypsum drywall would be to manufacture new drywall from scrap drywall, whereas, a lower value market, and a more common option, may be using the drywall as an agricultural soil amendment. Undeveloped markets are one of the main limitations that hinder recycled material use in higher value markets.

A local government may experience undeveloped markets due to multiple reasons, such as a lack of processing infrastructure, consistent material flow for the processing facilities to operate on a dependable schedule, or financial incentive. Options exist to overcome challenges and grow material markets. Options for municipalities and supporting case studies are discussed below.

- Implement bans to landfilling C&D materials before they go through a processing facility. Banning materials may foster an environment where markets are developed as an alternative to landfilling.
- Establish an ordinance requiring a percentage of C&D material to be diverted or recycled.
  - ⇒ Case study: A California ordinance requiring diversion of C&D is provided below.
- Install an ordinance requiring structures to be deconstructed instead of demolished. Deconstructing creates source separated and clean C&D waste, thus providing the markets with higher quality material.
  - ⇒ Case study: Portland, Oregon utilizes this strategy, as described below.
- Include recycling C&D rates in overall MSW recycling rates. C&D materials are typically heavy in mass, so recycling these materials is ideal when working to increase the recycling rate and grow the material markets.
  - ⇒ Case Study: Florida included C&D material recycling rates in overall recycling rates in efforts to meet recycling rate goals, as described below.
- Require that haulers transport C&D material to certified C&D MRFs for processing prior to landfill disposal.
- Require haulers to utilize certified recycling facilities. Certified means that the facility recycling rates are confirmed by a third party, preferably by a program

developed to an ISO level in order to help fraudulent recycling claims. Certified recycling facilities are further explained in Section 5.1.4.

- Provide loans or grants for C&D recyclers to expand their processing capabilities. Often the equipment necessary to sort and process mixed C&D loads at C&D MRFs is costly since certain equipment is used to process a single material. C&D recyclers may increase their recycling capabilities and participate in additional markets by purchasing equipment.

  ⇒ Case Study: Massachusetts Department of Environmental Protection (MassDEP) runs a grant program that financially supports facilities expanding their waste processing capabilities, described below.

- Create legislative diction that supports recycling efforts. C&D materials have different processing requirements compared to MSW. Clearly outlining the management of C&D in legislation may prevent C&D recycling from being overlooked and ultimately increase recycling rates.

- Organize communication between generators, haulers, and manufacturers to create a closed loop system. This type of system is when materials generated have an established path to manufacturers that can process materials into new products and then once these products become waste, then are again recycled into new products. The goal is to continuously recycle the materials, and if the materials leave the loop, they are to be recycled into a final product and not landfilled.

  ⇒ Case Study: Building Product Ecosystems LLC (BPE) coordinated efforts between construction contractors and hauler of C&D material, resulting in closed loop system for gypsum drywall. The case study is provided below

- Encourage construction of C&D MRFs by waiving fees associated with permitting.

- Provide grants for business that shift from using virgin materials to recovered materials. These grants help overcome cost issues in instances where virgin materials are more cost efficient than incorporating recycled material.

- Local governments and C&D recyclers can work together to commission studies by technical experts to identify potential end-uses of recovered C&D materials.

- Promote to businesses residents and agencies that recovered C&D materials may be used in their projects. Local governments may provide workshops and training regarding the types of recovered C&D materials that meet technical requirements for their projects

- Require construction projects to track generated and recycled quantities.

Case Study: California C&D Material Diversion Ordinance

The California Green Building Standards Code (GBSC), also known as CALGreen Code, was established in 2011. GBSC is a set of regulations within the California Building Standards Code and applies to construction projects in California. The code provides guidelines for sustainable building techniques and resource conservation throughout the planning, design, and construction stages of a structure.

Current CALGreen standards require 65% or more, by mass or volume, diversion of C&D waste. Both residential and non-residential projects are required to complete a waste material management plan or contract a waste management company to assist in material diversion. If local diversion rates are stricter than CALGreen code, the project must adhere to the municipal regulations (California Building Standards Commission, 2019).

A municipality that has stricter regulations is San Francisco. In 2006, San Francisco declared an ordinance banning C&D material from entering landfills, thus 100% diversion. If the C&D materials are source separated at the generation site, the materials must be brought to a recycling facility. If the debris is mixed, a Registered Transporter must take the material to a Registered Facility. Registered Transporters are haulers that are registered with the city and can prove that they did not dispose of materials at a landfill. A Registered Facility is a processing facility that are inspected regularly and can verify recycling rates of 65%, by mass (San Francisco Dept. of the Environment, 2006). These extra measures taken by San Francisco serve to maximize diversion of C&D materials from landfills.

Case Study: Portland, Oregon Deconstruction Ordinance

In efforts to create a consistent supply of C&D materials for the recycling markets, the city of Portland, Oregon established an ordinance in 2016 requiring structures to be deconstructed instead of demolished. Certified Deconstruction Contractors (CDC) are contractors eligible for hire by the homeowner and are licensed by the Oregon Construction Contractors Board (CCB) to conduct deconstruction projects. Per the ordinance, CDCs must complete the deconstruction process. Requiring CDCs ensures deconstruction protocol is followed and C&D materials are properly salvaged, i.e. diverted from disposal to a landfill. The ordinance also mandates a Post-Deconstruction Form to be completed by the CDC, post deconstruction process. This form documents the salvaged, recycled, and disposed materials generated from the deconstructed structure (City of Portland, 2016). This ordinance was created to promote source separation of materials and ultimately increase the C&D recycling rate. An example of a structure following Portland's ordinance is a 1,562 square foot home that when deconstructed, 80% of the structural materials were salvaged. Materials salvaged included insulation, wood framing/flooring, roof sheathing, doors, windows, and trim.

In 2018, Portland's Bureau of Planning and Sustainability released a status report pertaining to the deconstruction ordinance. Within the year of the ordinance being in effect, 80 homes were permitted to be deconstructed, an increase from the average of 20 homes pre-ordinance. Also, roughly 70% of the C&D mass, not including concrete, generated from these deconstruction projects was salvaged and or eligible for recycling. The deconstruction workforce also grew. After the ordinance went into effect, the number of contractors increased from the 3 contractors that conducted demolition projects to 17 CDCs (City of Portland, 2019).

Deconstructing a structure as opposed to demolishing results in the debris material to be separated on site, ultimately reducing contamination of material eligible for reuse and recycling. Generating clean C&D material increases options for diversion from landfills and easier handling at MRFs.

Case Study: Florida Includes C&D Recycling in Overall Recycling Rate

States and municipalities can increase recycling rates by including recycled C&D quantities in the overall recycling rate. In 2008, Florida established a 75% mass MSW recycling rate goal by 2020. As benchmark dates passed and counties were not meeting goals, recycled C&D rates began to count towards the overall recycling rate.

Table A. C&D materials currently accepted for recycling within Florida.

What Counted Then (Prior to 2012)	What Counts Now (2012- Present)
Concrete from residential/commercial buildings construction or demolition used for: • Road Base • Pipe Bedding • Drain Fields • Septic Tanks • Landfill Cell Drainage & Stabilization • Artificial Reefs Wood & Land Clearing Debris used for: • Mulch • Compost Final Cover Wood & Land Clearing Debris sent to: • Processed Fuel/Biomass Facilities	Concrete from residential/commercial buildings construction or demolition used for: • Road Base • Pipe Bedding • Drain Fields • Septic Tanks • Landfill Cell Drainage & Stabilization • Artificial Reefs Wood & Land Clearing Debris used for: • Mulch • Compost Final Cover Wood & Land Clearing Debris sent to: • Processed Fuel/Biomass Facilities Concrete from: • Roads • Bridges • Sidewalks • Curbs • Storm/Sewer Pipes • Culverts Concrete from building construction or demolition used for: • Lake Fill • Land Fill Wood & Land Clearing Debris • WTE Fuel • Daily Cover • Intermediate Cover • Landfill Roads Within a Cell Wood & Land Clearing Debris sent to: • WTE Facilities • Renewable Energy Facilities (other than WTE) Asphalt (not being directly reused)
*Effective in 2012, the red text represents additional materials and/or uses that count towards the recycling goal.	

In 2016, Florida mandated that any facility, disposal or MRF, must complete a Certification of Economic Feasibility form once a year. On the form, C&D materials entering and leaving the facility are documented. An economic assessment is also done in which the cost to recycle the incoming materials is analyzed. Requiring facilitates to evaluate the cost of recycling may decrease the amount of C&D sent straight for disposal and increase the municipalities' recycling rate (FDEP, 2016).

Case Study: Florida Includes C&D Recycling in Overall Recycling Rate Continued

As explained previously, accepting C&D materials for recycling can impact a state's overall recycling rate. In 1998, C&D material recycled into filling material for lakes as well as asphalt and concrete used in road projects were no longer included in Florida's recycling rate. Recycled C&D materials were added into recycling rate in 2012.

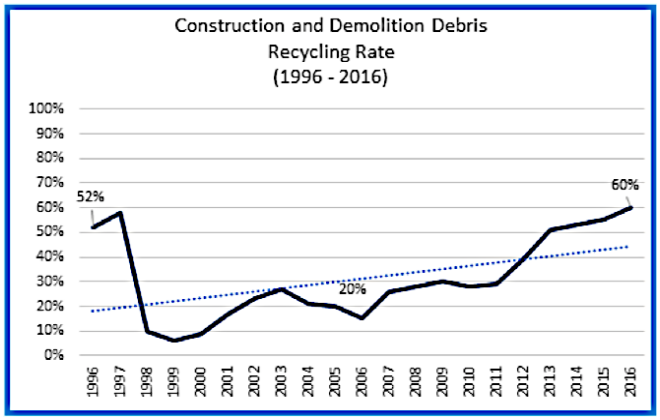


Figure A. Florida's C&D recycling rate for 1996-2016 (FDEP 2016).

Case Study: Massachusetts Grant Program

State governments can provide grants to companies in pursuit of expanding their C&D processing capabilities. For example, the Massachusetts Department of Environmental Protection (MassDEP) operates the Recycling Business Development Grant (RBDG) Program in which material processing companies can apply for grants that will pay for updating or implementing new machinery. Companies receiving grant money are required to meet expected processed tonnage throughout two years. Grant programs such as the RBDG incentivize local companies to increase recycling as a larger quantity of C&D material or a material that requires specialized equipment can now be processed with updated machinery. Increased material processing results in decreased landfilled material. Another benefit to programs such as the RBDG is that jobs may be created as the facility can accept more materials, more people are needed for processing.

In 2019, MassDEP administered a total of $600,000 to four waste management or processing companies, two of which were C&D processing facilities. New England Recycling Company, Inc. received $100,000 to advance their efforts in recycling mixed C&D waste by installing a B-line processing system. A B-line system allows for the mechanical processing of wood material under a desired size limit, and the installation is expected to result in 4,000 tons of wood separated for recycled instead of landfilled. Another recipient of the RBDG, Recycling Solutions of Raynham LLC, received $100,000 to advance their processing capabilities of wood. The company goal is to install a processing line which will result in 7,500 tons of wood to be separated from the mixed C&D received at the facility and then recycled (MassDEP, 2019).

Programs such as the RBDG program help support C&D material market growth within a municipality as updated and newer machinery allows for a wider range of materials to be processed. The program also builds connections between the government and local businesses, resulting in more organized and efficient efforts in managing C&D recycling.

Case study: Closed Loop Gypsum Drywall System, NYC

Building Product Ecosystems LLC (BPE) is a NYC based company that works to build connections between C&D generators, haulers, recycling, and manufacturing facilities. Efforts include creating a close looped material systems, in which materials generated at a construction site is collected and sent to a processing facility to then be recycled into a new product. The goal is that the cycle continues. BPE conducted a pilot program at a NYC construction site through collaborating with the project's contractor. For the construction project, BPE coordinated source separated collection of gypsum, in which gypsum is collected separately from other C&D. During the pilot program, the contractor did not use usual disposal method in which all waste materials is collected at once, compacted, and then landfilling. Instead, a team collected gypsum drywall first before the mixed C&D was removed. Source separation leads to less contaminated waste and thus a more economically appealing product for the recycling facilities

BPE works to create a fluid closed loop system. The company created a map of gypsum drywall generation sites, wallboard manufacturers, haulers, and gypsum specific processing facilities. Other efforts, specifically aimed at the gypsum drywall lifecycle, include collaboration with organizations such as the CDRA and the Gypsum Association to begin writing standards for recycling gypsum scraps. Standards provide manufacturers with protocol on economically recycling scraps into new gypsum wallboard (BPE, 2019).

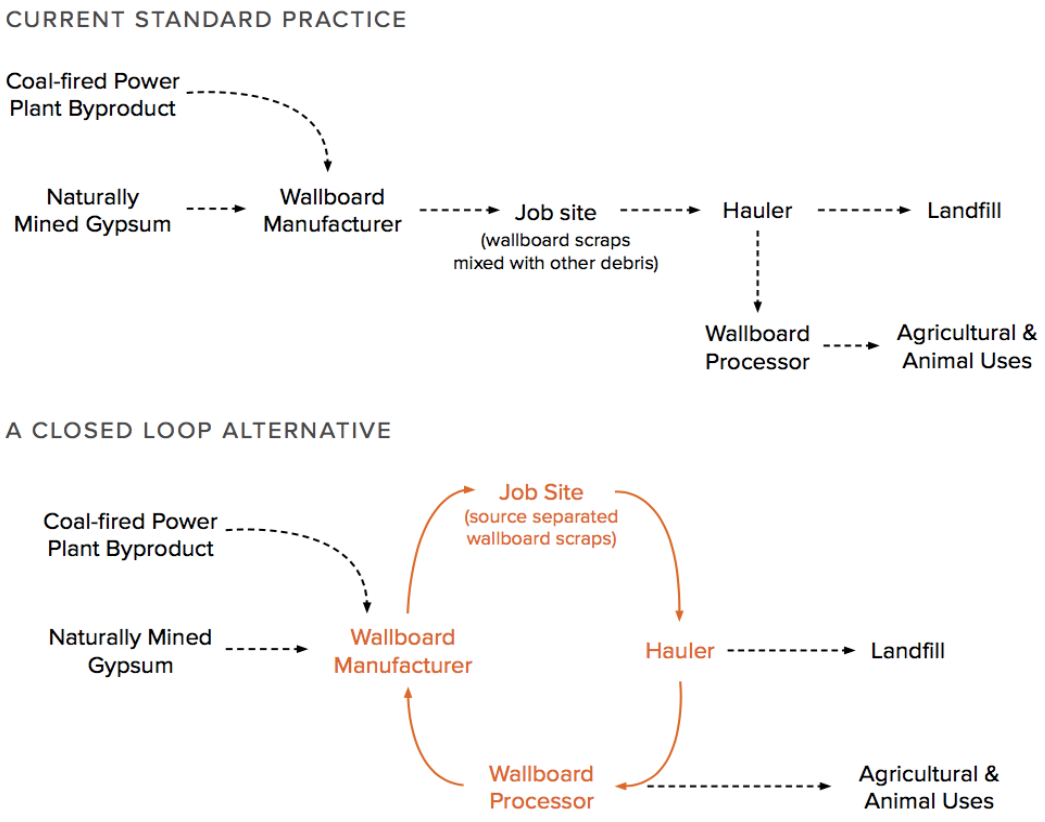


Figure B. Comparison of common disposal methods versus a closed loop method.

5.1.2 Competitive Economics

A municipality can help make recycling an enticing option compared to disposal methods, such as landfilling. Competitive costs of landfill disposal or using virgin products may present a challenge to successfully implementing C&D recycling. In many cases, the costs of disposal is less expensive than the costs of recycling C&D materials. Similarly, vendors may find purchasing virgin materials cheaper than purchasing recovered C&D materials. Local governments may implement landfill taxes on unprocessed C&D materials to incentivize C&D material processing at a C&D MRF before attempting to dispose at a landfill. The municipality may also adopt an ordinance that requires business and residential contractors constructing or demolishing buildings to deposit money based on the amount of expected waste. The project must recover and recycle a certain percentage of the debris in order to receive the deposited amount back. Other options are that local governments may place a tax reduction on recovered materials to encourage their purchase over virgin materials or fine building projects that do not meet diversion rates set by state or local ordinances.

5.1.3 Material Hauling

Hauling is the collection of materials. C&D is collected differently than curbside, which uses set routes on regular days. C&D is collected from construction and demolition projects that that change on a regular basis. Hence, while the collection of MSW it can make sense to set up a franchise system that allow only one company's set of trucks to go down collection trucks to go down the street instead of having several companies do that, for C&D it doesn't matter what company collects the material, it is always going to be a truck doing that.

When collecting C&D debris, haulers follow one of three systems that the county or city has established; an open market, non-exclusive franchising, or exclusive franchise. These hauling systems are described below. The type of system the jurisdiction chooses is highly variable within a state. With all three systems, the hauler typically provides the bins or roll-off boxes to the customer. Local governments can include in their ordinances or contracts with haulers that C&D waste must be first transported to C&D MRFs for processing prior to landfill disposal. Ensuring that recyclers receive the material from haulers may result in a higher quantity of processed and recovered C&D materials.

5.1.3.1 Open Market

An open market system entails that all C&D waste haulers are to regulate themselves and operate independently, as long as they adhere to any state standards. For example, California instituted the CALGreen building code standards, further discussed in Section 5, mandating 65% waste diversion for commercial and residential construction projects. Contractors must choose a C&D hauler that can satisfy the mandate. Hauler companies are in charge of where they bring their materials. A subsection of the open market is flow

control in which any hauler can operate, but the location of material drop off is mandated by the municipality. For instance, the State of Washington has a flow control system in place. If the material is to be recycled at a recycling facility, the generator can hire any hauler to pick up the material. If the material will be landfilled, a franchised hauler must collect the waste.

5.1.3.2 Non-Exclusive

Non-exclusive franchising is a system where customers within county limits can choose their C&D hauler, as long as the hauler is registered by the local government. The term “pay-to-permit” describes that once registered, the hauler pays a percentage of the gross income to the municipality in order to operate. Within non-exclusive franchising, the county or city may require all registered haulers to provide a specified level of recycling for the customer and documentation of recycled quantities (County of Los Angeles Dept. of Public Works, 2012).

5.1.3.3 Exclusive Franchising

Exclusive franchising occurs when the city allows for one company to have complete hauling rights to a zone within municipality limits. The municipality and the hauler agree on the price rates. The hauler pays an upfront fee and then a certain percentage of gross income for the rights to service the zone. The contract can run for multiple years. Exclusive franchising is of concern for municipalities because there are decreased opportunities for innovative recycling solutions. For example, a hauler company can control a commercial area for an extended period of time. Control over a long period of time may lead to a lack of incentives for the hauler company to increase recycling rates. Also, recycling facilitates that have more advanced technology to sort and process material categories may not be used if the franchised hauler drops off material at other facilities more economically beneficial to the hauler, even if that facility is farther away. Lastly, if the exclusive hauler has a contract with a specific disposal site, such as a landfill, the hauler may choose to bring the C&D material there and not utilize a recycling facility. These issues will lead to recycling opportunities not maximized.

5.1.4 Certifications Supporting Recycling

Municipalities can recommend or require that construction projects meet building standards and achieve certifications related to the quality and efficiency of the project. Examples of available certifications include Leadership in Energy and Environmental Design (LEED) and the Total Resource Use and Efficiency (TRUE) Zero Waste certifications. These certification programs award points to buildings based on the construction, operation, C&D debris management, energy usage, and resource efficiency. A common waste management strategy within these programs is to track the mass or volume flow throughout the generation, disposal, and recycling steps. A detailed overview of these certifications is provided below.

Certification of recycling rates is also important. Utilizing recycling facilities that have their recycling rates certified by a third party, especially pertinent for

C&D haulers, may be useful for increasing recycling culture and efforts. The Certification of Recycling Rates (CORR) program was established to provide credible, ISO-level third-party certification of C&D facilities' true recycling rates. ISO stands for International Organization for Standardization. CORR is administered by the Recycling Certification Institute (RCI). RCI was created to meet this growing need for reliable recovery and recycling reporting by C&D recycling facilities. Accurate recycling numbers also helps municipalities plan improvements on their recycling programs.

Case Study: LEED and TRUE Certifications

Building certifications promote recycling markets as achieving certifications is respected and to obtain such certification, efficient C&D debris management must occur. LEED and TRUE are two examples of certifications available.

Construction project can obtain a Total Resource Use and Efficiency (TRUE) certification. The purpose of TRUE is to regulate the project's waste through diversion efforts and ultimately result in a zero waste structure. To receive the certification, 7 requirements must be met and then an additional 31 points must be achieved through planning and diversion efforts (Green Business Certification Inc., 2017). Examples of requirements/ point opportunities include:

- Any waste must be under the 10 percent contaminated threshold
- A 90% diversion rate of total waste materials (inclusive of C&D waste) through prioritizing recycling
- Monitoring where every hauler of recyclable material is sending the waste

LEED, Leadership in Energy and Environmental Design, is a certification awarded to structures that implement sustainable design features and meet cost and environmental efficiency standards. The U.S Green Building Council (USGBC) operates the LEED program. The most current version, LEED v4, was released in 2013. LEED certifications are tailored to the type of project, such as building design and construction, interior design and construction, and building operations and maintenance.
Structures can obtain points through meeting credit opportunities such as:

- Utilizing processing facilities registered under Recycling Certification Institute's, RCI, certification program Certification of Recycling Rates (CORR). The CORR program ensures that the recycling company is audited by a third party and recycling values are accurate.
- Diverting 50% or 75% of C&D waste, either by mass or volume, from disposal methods.
- Implementing construction and demolition waste management planning: A written outline considering the materials that will be diverted (minimum 5), projected waste of these materials (%), how these materials will be handled once becoming a waste (either source separated on site or mixed), destination of materials, end of life product made from the recycled materials, total diversion rates
- Building Life-Cycle Impact Reduction: Reuse of 25-75% of building materials
- Note: fines from material processing and used as Alternative Daily Cover (ADC) for landfills cannot be included in waste diversion calculations.

A structure can achieve 1 of 4 levels of certification based on the points obtained throughout design, construction, and operation stages. The four levels are; certified (40-49 points), silver (50-59 points), gold (60-79 points), and platinum (80+ points) (USGBC, 2019).

The accountability of recycling and processing facilities is highly stressed in both of these programs. LEED and TRUE awards work to decrease the need of virgin materials through advocating recycling options (US Green Building Council, 2019).

5.2 Markets and Opportunities

5.2.1 Portland Cement Concrete

Portland Cement Concrete (PCC) can replace natural stones as the coarse aggregate component of new PCC, often in road and building construction. Recycled PCC used as an aggregate is called Recycled Concrete Aggregate (RCA). In many states, the Department of Transportation (DOT) provides specifications for use of crushed concrete in road base or similar applications. The use of crushed PCC as an aggregate in new PCC

pavement has been explored, but lack of established and widespread DOT specifications has limited this practice in the US. Other common uses of PCC include rip-rap for erosion control, clean fill material, and artificial reefs. Florida is an example in which PCC is used for Florida Department of Transportation (FDOT) projects and a case study is provided at the end of Section 5.

Figure 29. Crushed concrete is commonly used as a replacement for construction aggregate

5.2.2 Asphalt Pavement

Reclaimed asphalt pavement (RAP) is created when asphalt roads and asphalt shingles are recycled into new hot mix asphalt pavement. Most of this material remains controlled within the boundaries of the asphalt paving industry.

5.2.3 Wood

Reuse of wood is highly dependent on the type of wood, moisture content, and contamination level. Much of the wood in the C&D universe is mixed in with other materials. The wood must be separated out, either through source separation or at the processing facility, to meet desired product quality. Most wood does not get recycled into new structural components but can be recycled into animal bedding, mulch, or turned into biomass fuel. An example of Arizona recycling wood into biomass fuel for energy production is provided at the end of Section of 5. Wood has long been used as a fuel, and woody biomass should be used to help achieve the goals of any zero waste program

5.2.3.1 Dimensional Lumber

The dimensional lumber category includes wood that is painted, unpainted, treated with preservatives, or not treated. If unpainted and not treated, the wood has a higher market appeal. Painted wood is of concern due to the potential presence of lead. Treated wood is of concern for uses such as mulch since the arsenic and other chemicals may then be further exposed to the environment.

5.2.3.2 Engineered Wood

Due to the use of preservatives in engineered wood, the material is generally marketable as biomass fuel source for industrial facilities or power

plants. The wood has a lower moisture content, and ultimately providing higher amount of energy, in BTU.

5.2.4 Asphalt Shingles

Asphalt pavement is a common market for asphalt shingles. In some parts of the US, asphalt shingles are heavily recycled as an ingredient in the production of new asphalt pavement, while in other areas it is difficult to find a company that will accept the material. Prior to use in the asphalt pavement production process, the shingles must be adequately processed, including removing foreign materials, grinding, screening, and nail removal with a magnet. Shingle processing for recycling occurs either at fixed facility locations or through mobile grinders. While the type of equipment used to process shingles is similar to those used for other C&D materials (such as wood), some vendors specifically market size reduction equipment as ideally suited for shingle processing.

A developing market for asphalt shingles is dust control on gravel roads. The shingles are ground to a smaller size and then mixed with sized aggregate. The mixture is placed on the gravel road. It is an economical alternative to current methods.

5.2.5 Gypsum Drywall

Some manufacturers may recycle portions of their scrap drywall into new drywall, but more commonly, gypsum is used as a soil amendment since it is a source of calcium and sulfur. The gypsum can be made into a powder or a pellet and marketed for agricultural use. The material is also used in PCC since the gypsum is a primary ingredient. However, this practice is still restricted since there is a lack of constant supply of scrap drywall. Gypsum from drywall is still frequently landfilled, and there exists many issues associated with gypsum such as the formation of toxic hydrogen sulfide gas.

5.2.6 Metal

Scrap metal recycling is a major industry in the US, and much of this material comes from metal once found in buildings or other infrastructure. Historically large quantities of C&D metals were targeted for removal prior to demolition and recycling. Demolition contractors often target this metal for removal because of a high market value. When mixed with other debris, C&D recycling use magnets for ferrous metals and eddy currents to extract non-ferrous metals. The scrap metal market is well established and C&D recycling operators will market their metals to these facilities or through brokers.

5.2.7 Fines

When used as alternative daily cover at landfills, C&D fines reduce the amount of clean soil that needs to be used. C&D fines that meet necessary chemical characteristics have also been used as a substitute for clean soil in non-structural fill applications. Much of the remaining material on a C&D processing line that is of fines size has a high calorific value and thus has the potential to be used as a fuel source.

Case Study: Portland Cement Concrete as Recycled Concrete Aggregate

Road structure construction is a common market for C&D material, specifically Portland Cement Concrete (PCC). The U.S Department of Transportation Federal Highway Administration (FHWA) oversees the integration of recycled C&D material into transportation structures, such as roads. The standards for recycled C&D material in transportation structures varies per Department of Transportation (DOT).

The Florida Department of Transportation (FDOT) Standards Specifications for Road and Bridge Construction provides design requirements for recycled PCC used as a Recycled Concrete Aggregate (RCA) for new PCC. A component of concrete is coarse aggregates, usually consisting of stones. RCA can be a replacement for the course aggregate component within PCC, depending on the aggregate size requirements for the new batch of PCC. Recycled PCC can be considered as RCA if sourced firsthand from a concrete pavement structure, the construction or demolition project had been permitted by DEP and FDOT, or if DEP has approved the source to be a producer of clean debris. The RCA must also not contain other C&D materials by the specified weights below. An excerpt from FDOT Standards Specifications for Road and Bridge Construction regarding RCA is provided below (FDOT, 2019).

911-2.7 Recycled Concrete Aggregate (RCA) Composition: RCA shall consist of concrete material derived from the crushing of hard Portland cement concrete. In addition to the deleterious materials noted in 911-2.2, RCA shall be asbestos free. The following limits shall not be exceeded:

Bituminous Concrete...……..……1% by weight
Bricks……..……..……....1% by weight
Glass and Ceramics…..……..…..1% by weight
Wood and other organic substances…....0.1% by weight
Reinforcing steel and welded wire fabric…0.1% by weight
Plaster and gypsum board……0.1% by weight

Florida currently directs 100% of PCC waste into FDOT projects. Other opportunities to utilize crushed PCC include rip rap and as drainage material.

Case Study: Arizona Tax Credit for Renewable Energy Sources

Renewable energy, such as burning biomass, decreases dependence on fossil fuels, and can utilize wood debris. As wood is a common C&D debris, diverting the debris to be used as a fuel source instead of being disposed in a landfill supports the wood recycling market. Tax credits provided by the state or municipality is method to stimulate these diversion efforts.

The Renewable Energy Production Tax Credit Program (PTC) was established federally in 1992 and the purpose was to economically incentivize taxpayers to generate renewable energy. Arizona participated in the tax credit program from 2010 until 2017 when the PTC program ended for non-wind renewable energy generators (Congressional Research Service, 2017). To receive the credit, the generator was required to produce at least 5 megawatts of energy per year. Producing renewable energy via burning biomass was a way for people of Arizona to receive a tax credit, and in turn recycle C&D wood debris. Exclusions for wood for the PTC program included wood material that was pressure treated, contaminated with plastics, painted, or chemically treated.

An excerpt of the tax credit is provided below.

For a qualified energy generator using a wind or biomass derived qualified energy resource (A.R.S §§ 43-1083.02(D)(1) and 43-1164.03(D)(1)) the amount of the income tax credit is:

- 1¢ per kilowatt-hour of the first 200,000 megawatt-hours of electricity produced. (200,000 megawatt-hours of electricity equals 200 million kilowatt-hours which, when multiplied by 1¢ per kilowatt-hour, equals $2 million in credit.)
- The tax credit cannot exceed $2 million dollars per year per facility that produces electricity (ADOR, 2016).

Overall, the PTC created a market for C&D wood waste and wood waste fulfilled the need of biomass energy generators for a dependable incoming source of fuel.

6 SUMMARY

Based on the information provided in Section 5, below is a list of approaches local governments may follow to more successfully implement C&D recycling in their community.

- Integrate recycling incentives or requirements into the local building permit application process (e.g., requirement to meet a target recycling percentage, deposit that is only refundable if a recycling target is met).
- Structure C&D collection franchise agreements to include recycling companies.
- Educate the general public about the advantages of recycling C&D, and how and where to do it for their own DIY projects. Also provide information on how to recycle bulky materials, such as mattresses and furniture.
- Require processing of C&D at a recycling facility prior to disposal. Incentivize or require that buildings be constructed to meet certification requirements of programs such as Leadership in Energy and Environmental Design (LEED) certification.
- Adopt requirements that new construction projects must use and track the use of materials with recycled content.
- Develop technical construction specifications for roads that consider recycled C&D materials.
- Foster market development for recovered C&D materials (e.g., offer grants to business to shift to using recycled materials, etc.)
- Require C&D haulers use CORR certified recycling facilities in order to insure the material is actually getting recycled.
- Administer loan programs to C&D recyclers to expand their processing capabilities (e.g., purchase equipment, etc.)
- Commission studies to identify potential end-uses for recovered C&D materials.
- Waive permitting fees associated with constructing C&D recycling facilities.
- Provide workshops and training to business regarding their communities C&D recycling opportunities.

7 RESOURCES

7.1 State Regulatory Profiles

In 2018, the CDRA Executive Committee Board of Directors launched a "50 State Regulatory Profile Initiative." The goal of the initiative was to provide CDRA members with access to regulatory information affecting C&D recycling in all 50 states in one convenient location.
For more information, contact or visit:
www.cdrecycling.org/state-profiles
Email: info@cdrecycling.org
Call: 866-758-4721

7.2 Recycling Certification

Certification of Recycling Rates (CORR) is available for recycling facilitates. For more information, including scheduling a recycling rate certification or to register your facility with the Institute, contact or visit:
www.recyclingcertification.org
Email: info@recyclingcertification.org
Call: 1-916-242-8287

7.3 Material Websites

CDRA continues to focus on maintaining a vision for the future for C&D debris recycling over disposal. The Association has worked in coordination with the recycling industry and others to develop websites specific to asphalt shingle, concrete and gypsum drywall recycling.

Concrete Recycling for more information,
visit cdrecycling.org/materials/concrete/

- Drywall Recycling for more information, visit cdrecycling.org/materials/gypsum-drywall/
- Shingle Recycling for more information, visit www.shinglerecycling.org/
- Asphalt Pavement Recycling for more information, visit cdrecycling.org/materials/asphalt-pavement/

7.4 Whitepapers and Guidelines

CDRA contracted with the University of Florida to develop documents that provide information regarding the benefits of recycling and guidelines for recycling gypsum drywall. These are available to CDRA members through the CDRA website. For more information, visit cdrecycling.org/resources/.

- How to Better Manage and Market C&D Fines (Townsend et al., 2018a).
- How to Better Manage and Market Asphalt Products (Townsend et al., 2018b).
- CDRA Benefits of C&D Recycling (Townsend et al., 2017).
- Standard Specifications for the Production of Recycled Gypsum from Scrap Gypsum Drywall Version 2.0
- How to Develop End Markets for Recycled Products

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