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Waste Management at the Construction Site

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1. Introduction

Construction and demolition (C&D) debris is produced during the construction, rehabilitation, and demolition of buildings, roads, and other structures (Clark, Jambeck, and Townsend; 2006). According to the U.S. Environmental Protection Agency (2003), C&D debris amounts to 170 million tons per year, or 40 percent of the solid waste stream in the U.S. While efforts to reduce this through reduction, recycling, reuse, or rebuying continue to expand through government mandates, green building incentives, and education, much work remains to be done. This chapter will begin with a history of C&D debris management and will cover state and local government regulations that pertain to C&D debris. Impacts on this matter from green building programs will be described. Issues that pertain to landfills, including C&D landfills, will be evaluated, along with concerns that relate to specific materials. The chapter will conclude with a discussion of lessons learned to date and recommendations for improved progress.

2. Background

Waste generation by human societies is not new. "Since humans have inhabited the earth they have generated, produced, manufactured, excreted, secreted, discarded, and otherwise disposed of all manner of wastes" (Meliosi,1981, p.1). Working to devise methods for dealing with their societies' wastes has occupied humans since the beginning of civilization and the creation of cities. The ancient city of Athens, Greece had a regulation that required that waste be dumped at least a mile away from city limits; and ancient Rome had sanitation crews in 200 AD (Trash Timeline, 1998).

What is new is the amount of waste produced by human societies, especially industrial societies. Of course part of this is driven by the rise in human population. More people will create more waste. But the amount of waste created has soared since the industrial revolution and development of a culture and global economy driven by consumption.

The development of formal management strategies for the collection and disposal of solid waste in the United Sates has occurred primarily within the last 110 to 120 years. Early America had a relatively small population that was widely dispersed on the land and relied primarily on an agrarian-based economy. Few waste materials were produced, and every possible use was sought for materials before resorting to discarding anything.

As Susan Strasser notes in her book *Waste and Want: A Social History of Trash* (1999):

"most Americans produced little trash before the 20th century. Packaged goods were becoming popular as the century began, but merchants continued to sell most food, hardware and cleaning products in bulk. Their customers practiced habits of reuse that had prevailed in agricultural communities here and abroad. Women boiled food scraps into soup or fed them to domestic animals; chickens, especially, would eat almost anything and return the favor with eggs. Durable items were passed on to people of other classes or generations, or stored in attics or basements for later use. Objects of no use to adults became playthings for children. Broken or worn-out things could be brought back to their makers, fixed by somebody handy, or taken to people who specialized in repairs. And items beyond repair might be dismantled, their parts reused or sold to junk men who sold them to manufacturers"(p.12).

While the method Strasser describes above may have worked in the sparsely populated country side, it was not perfectly suited to cities. A brief review of references to the filth of American cities of the mid 19th century made in the historical record illustrates this. For example, in Washington D.C residents in 1860 discarded garbage and chamber pots into streets and back alleys. Pigs roamed free and ate the filth, and slaughter houses emitted putrid smells. Rats and cockroaches were common in most buildings in the city, including the White House (Trash Timeline, 1998).

It was not until the late 19th century that a concerted effort started to appear in the nation's cities to clean up streets and devise some formal strategies for managing the increasing amounts of waste. Prior to that period cities typically made due with an informal network of small firms and legions of the poor who worked to collect wastes (McGowan, 1995). Citizens seldom paid to have wastes hauled away, but instead placed them at curbsides where individuals from this informal network would go through them and remove anything considered to have residual value. Items deemed to have no value were often left in the streets or tossed into alleys to rot. Milwaukee, Wisconsin provides a specific example:

"Until 1875, hogs and 'swill children'- usually immigrant youngsters trying to supplement the family income - collected whatever kitchen refuse Milwaukeeans produced. Obviously unequal to the task of collecting the wastes of an entire city these 'little garbage gatherers' left the backyards and alleys reeking with filth, smelling to heaven" (Leavitt, 1980, p. 434).

While most cities of the 19th century had no formal means of collecting and managing solid wastes, many had dumps. But they were basically open pits in the ground. Swamps were also often used as dumping grounds. Melosi (1981) cites a description given by Reverend Hugh Miller Thompson in 1879 that described a dump in New Orleans this way:

"Thither were brought the dead dogs and cats, the kitchen garbage and the like, and duly dumped. This festering, rotten mess was picked over by rag pickers and wallowed over by pigs, pigs and humans contesting for a living in it, and as the heaps increased, the odors increased also, and the mass lay corrupting under a tropical sun, dispersing pestilential fumes where the wind carried them" (p.545).

But as the industrial revolution in the United States progressed, and with the ensuing development and soaring population growth in cities across the country, cities were forced to seek more formal methods for managing wastes. In New York City in 1880 scavengers removed 15,000 horse carcasses from the streets (Trash Timeline, 1998). It was not just horse carcasses that created a problem on city streets. Engineers of that era estimated there were 26,000 horses in Brooklyn that produced 200 tons of manure and urine each day (Melosi, 1981). Most of that was deposited and left in the streets. In 1892, Milwaukee, Wisconsin citizens were in an uproar because the city's drinking water supply, drawn from Lake Michigan, had become polluted by trash and waste being dumped into the lake (Leavitt, 1980).

Driven by the waste problems illustrated by the above example, American cities began to set up trash collection programs to deal with wastes generated by their citizens. In 1880 43% of U.S. cities had a municipal program or paid private firms to collect trash. By 1900 this had increased to 65% of cities (Melosi 1981). However, there were seldom regulations on how the waste would be disposed. Many times private haulers removed any items with residual value while collecting wastes and dumped everything else in the nearest vacant lot or body of water.

As waste generation rates continued to grow and citizens complained about filthy streets and polluted water supplies, municipalities were forced to begin devising disposal methods to end these problems. The spread of disease and resulting large death toll in urban areas also spurred action. Medical thinking for much of the 19th century relied on the filth theory of disease to explain the cause of epidemics. During this time period, "most physicians believed that rotting organic wastes in crowded urban areas produced a miasmatic atmosphere conducive to the spread of diseases such as cholera, yellow fever, diphtheria, and typhoid fever" (Leavitt, 1980, p.461). This theory, even though incorrect, helped create a health justification for garbage reform (Leavitt, 1980). This is also why one of the most preferred methods of garbage and trash disposal at the turn of the century was incineration. Burning garbage and trash would sanitize it before it was hauled to a dump (McGowan, 1995). Incineration also reduced the amount of material that needed to be dumped.

Between 1900 and 1918 a national movement arose to create municipal refuse departments and bring "professional engineering and management know-how to the garbage business" (McGowan, 1995, p.155). A man named George Warring is often cited as one of the first to implement this idea in a major city. An engineer with a military background, he was appointed Sanitary Commissioner in New York City in 1894. Warring had earned a national reputation for his work in designing a modern sewage system in Memphis, Tennessee. He had been sent to Memphis by the National Board of Health after a yellow fever and cholera epidemic killed more than 10,000 people. When he came to New York he set about cleaning up the city streets and designing and building facilities to handle the city's collected garbage and trash (Melosis, p.56).

Warring had a waste recovery facility built. It consisted of a conveyor belt where immigrant laborers sorted through trash for any items of value as it passed by. The conveyor belt was powered by steam created with heat from burning trash (McGowan citing Sicular, 1984). Reduction and incineration were the preferred disposal solutions for much of the country at the beginning of the 20th century. Even those municipalities that continued land dumping saw that only as a temporary solution until they could afford to construct sorting facilities and incinerators such as Warring had built in New York (Melosi, 1981).

As a method to assist sorting at recovery facilities, many cities required their citizens to sort and separate trash before placing at the curb for collection. Spielman (2007) provides an example of one municipality's"card of instruction for householders." Residents were required to use three receptacles when putting waste materials out for collection. One was to be used for ashes. However, sawdust, floor and street sweepings, broken glass and crockery, tin cans, oyster and clam shells were also to be placed in the ash receptacle. The second receptacle was to be used for garbage. This was defined to be kitchen or table waste, vegetables, meats, fish, bones or fat. The third category was rubbish bundles. This included bottles, paper, pasteboard, rags, mattresses, old clothes, old shoes, leather and leather scrap, carpets, tobacco stems, straw, and excelsior.

Many of these advancements were abandoned with the reduction of public funding resulting from the Great Depression. Cities were forced to reconsider how to collect wastes and continue the operation of sorting facilities and incinerators. Collecting separated wastes and running sorting facilities were expensive operations. But incinerating mixed wastes made that process much more costly. The moisture content of comingled waste made it less efficient to burn (McGowan, 1995). Sanitary engineers conducted calculations to compare the cost of burning trash with burying it. These calculations showed that the cost for burning waste was two dollars per ton, while the cost of burying it just $0.29 per ton (McGowan 1995, citing Thresher, 1939). It was not long before cities quickly abandoned waste recovery and incinerator facilities and moved to the widespread practice of using dumps. Ironically, New York City also led the way in abandoning the efforts of reformers like Warring, and reinstituted the method of dumping trash on the land. William Carey, the head of New York City Sanitary Department at that time, developed dumps throughout New York's five Boroughs (McGowan, 1995). Waste was no longer viewed as a source of materials, but instead seen as "an expensive nuisance that could not be ignored" (McGowan, 1995, p. 160).

In 1931 Fresno, Jean Vincenze, the newly elected Public Works manager, immediately canceled the city's incineration contract and began what he called the sanitary fill (McGowan, 1995). Vincenze's "sanitary landfills" were nothing like current day, lined sanitary landfills. Sanitary landfills of this era used a layering process. A layer of garbage 12 inches deep would be spread over the fill area and then covered with ashes or some sort of non-putrescent rubbish. This layering process continued until the area was completely filled (Melosi, 1981).

The cost for disposing the city's trash dropped dramatically as Fresno's public works department perfected the work of collecting, transporting, and covering each day's garbage. This allowed the public works department to both expand the number of residents served with trash collection services and reduce the costs for providing this service. As McGowan(1995) notes, "the low cost and simplicity of landfill operation allowed officials of waste management firms (public and private) to concentrate their efforts on cutting costs in the labor intensive area of collection and transportation" (p.161).

2.1 C&D debris in U.S. history

A brief search of historical literature reveals little information on construction and demolition debris or how it was handled in the 19th or early 20th century. This is not surprising, since even in 1993 construction and demolition waste was seldom recorded separately from municipal solid waste (Cosper *et al.,* 1993).

Even though the country was developing at a rapid pace in the late 19th century and much new construction was undersay, a significant amount of demolition likely resulted from this development. In the October 10, 1937 issue of the *New York Times*, a story reported that "in the year 1936 there were *demolished* in the City of New York more than 10,000 dwelling units in old-law tenements and an equal number will have been *demolished* in 1937. " (Post, 1937).

Construction and demolition debris in the United States would have consisted of relatively few types of materials in the 19th and early 20th century. For example, in Philadelphia during 1950 dozens of 18th and 19th century buildings were demolished to create open space for Independence National Historical Park. During archeological work done in the park in 2000, much of the construction debris from these demolished buildings was uncovered. It was composed of wood, stone, mortar, brick, plaster, and cement (Digging in the Archives, 2010). This archival post also notes that a portion of the demolition rubble was disposed of by burying it on-site. Evidence is also cited that much of the building rubble was transported by rail to Lancaster County, Pennsylvania, where it was used to fill in a lake (Digging in the Archives, 2010).

Dumping wastes into open dumps was the most common disposal method from the period of the Great Depression until well into the 1970s. In 1972 an EPA Administrator estimated that more than 14,000 municipalities across the country relied on open dumps for waste disposal (Melosi, 1981). None of these municipalities implemented even the most basic landfill technology and attempt to layer wastes or cover each day's accumulation of trash with fill. Many of these dumps were located in wetland areas, known more commonly before the environmental movement as swamps. Abandoned gravel beds, ravines, and gullies in the landscape were also commonly used. Dumps controlled by well-managed municipalities would cover each day's accumulation of dumped waste and garbage with clean fill as a method to reduce odors and limit vermin's access to food wastes. But most dumps were merely piles of waste open to the environment· And even the best-managed landfills had no linings to protect ground water or even surface water runoff from leachate. This method of disposal continued to be the most widely used across the country until the creation of the Environmental Protection Agency and its development of strict criteria for the construction and maintenance of sanitary landfills.

The Resource Conservation and Recovery Act of 1976 (RCRA) forced the closure of open dumps across the country and developed regulations that dictated minimum standards for the construction and maintenance of sanitary landfills (Trash Timeline, 1998). Current day sanitary landfills require a liner system of compacted clay or high density polyethylene. A leachate collection system is also required to collect this liquid from the bottom of the reservoir created by the liner. Methane gas collection wells are also required. Waste is placed over the liner and leachate collection system and then covered at the end of each day with six inches of soil or an alternative daily cover (NSWMA, 2008). In some cases, inert types of construction and demolition materials are used as a daily cover material.

The closure of these dumps across the country and the expense of constructing engineered sanitary landfills significantly increased disposal costs of municipal solid waste. The increased cost of disposal began to make recycling of materials an economically viable option. In fact, recovery of materials from the waste stream did grow. It went from very small amounts to about 30% by 1995 (Spiegelman and Sheehan, 2005).

As a further method to reduce the demand for landfill space, some municipalities began to limit, and in some cases ban, construction and demolition materials from their landfills as a method to conserve landfill space. C&D materials typically do not contain putrescible wastes that sanitary landfills are designed for. In addition, many materials in C&D waste can be recovered and recycled. But even as late as 1996 only 20-30% of C&D debris was recovered for reuse or recycling. The majority of the remaining material was land-filled (U.S. EPA, 1998).

In 2003 the United States Environmental Protection Agency estimated that construction and demolition debris totaled approximately 170 million tons (U.S. EPA, 2003). This amount is broken down as follows:

- **Construction: 15 Million Tons (9% of the total).** This refers to waste materials generated during initial construction.
- **Renovations: 71million tons (42% of the total). This includes** remodeling, replacements, additions, includes wastes from adding new materials and removing old materials.
- **Building Demolition: 84 million tons (49% of the total).**

Of these amounts, the following breakdown is made:

- Residential construction: 6%
- Non-residential construction: 3%
- Residential renovation: 22%
- Non-residential renovation: 19%
- Residential demolition: 11%
- Non-residential demolition: 39%

Figure 1 displays these figures graphically.

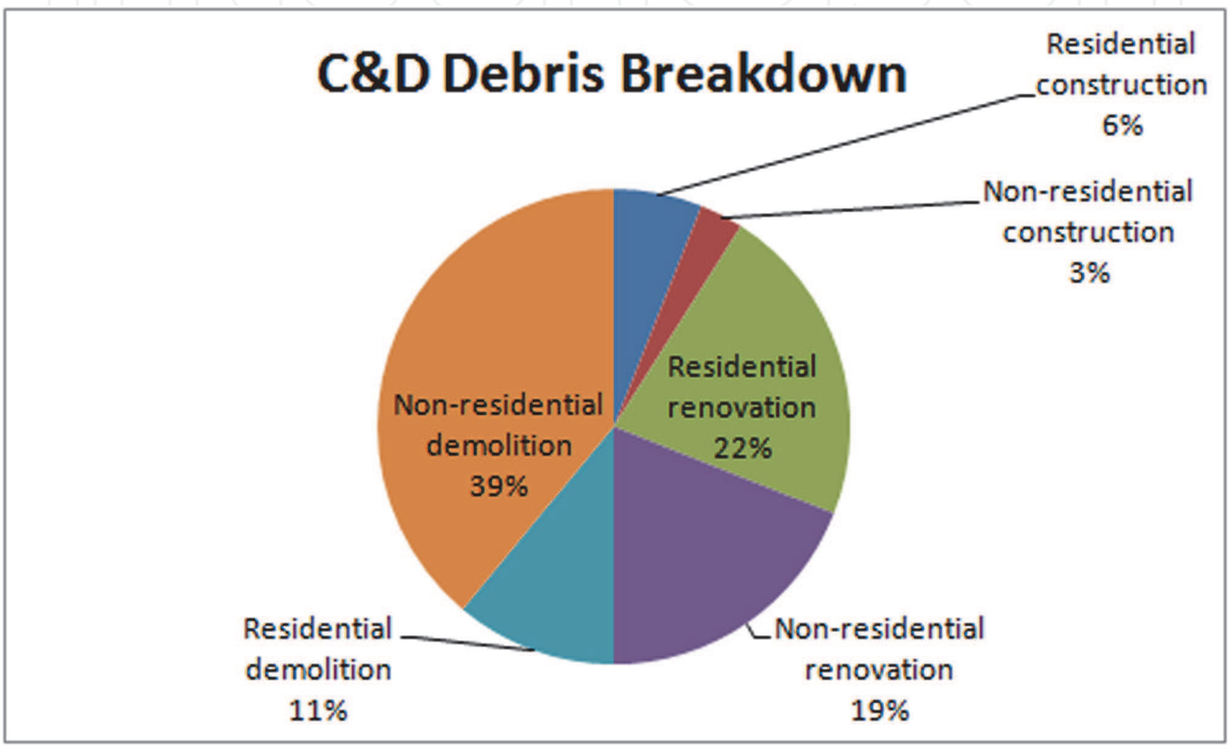

Fig. 1. C&D debris breakdown in the United States.

The EPA roughly estimates that 48% of C&D materials were recovered in 2003, which is 23% higher than the recovery estimate of 1997 (U.S. EPA, 2003). The agency also estimated that while much of the non-recovered C&D materials went to specifically designated C&D landfills, a significant amount also went to municipal solid waste landfills or incinerators. However, the amount of C&D waste co-mingled with municipal solid waste is not known (U.S. EPA, 2003).

2.2 Conclusion

Sustainability means that a community or society can continue to do what it is doing forever. But current rates of raw material inputs and energy consumption required to construct, maintain, and then dispose of buildings in the United States is certainly not sustainable for any extended period of time. And the widespread practice of simply burying construction and demolition materials instead of using those materials to reduce the amounts of raw materials extracted from the environment is a strategy that cannot be sustained indefinitely. In a world with an expanding global economy and the increasing demand for material resources, we must end the linear process currently used for material acquisition and use. We must find ways to imitate natural systems where there is no such thing as waste material, so that materials are constantly recycled and serve as inputs to the human economy or nourishment to the eco-system.

3. Federal regulations and C&D debris

While C&D debris is not explicitly regulated at the federal level in the U.S., the disposal of solid and hazardous waste is covered by the Resource Conservation and Recovery Act (RCRA) of 1976, which amended the Solid Waste Disposal Act of 1965. RCRA set national goals for:

- Protecting human health and the environment from the potential hazards of waste disposal.
- Conserving energy and natural resources.
- Reducing the amount of waste generated.
- Ensuring that wastes are managed in an environmentally-sound manner.

(U.S. EPA, 2010a)

Through the state authorization rulemaking process, the EPA has delegated RCRA implementation responsibility to individual states. Since the enactment of RCRA, other federal statutes have been passed that affect C&D debris, including the National Emission Standards for Hazardous Air Pollutants (NESHAP), which apply to asbestos, and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), also known as the Superfund, which applies to any hazardous material in C&D debris. The Toxic Substances Control Act specifically regulates the disposal of PCB ballasts in debris generated from activities related to renovation and demolition.

The 1970 Clean Air Act Amendments established NESHAP, through which the EPA is required to identify and list harmful air pollutants (EPA, 2010b). These standards require that emissions from these pollutants be minimized to the maximum extent possible through the Maximum Achievable Control Technology (MCAT). NESHAP specifies procedures for removing and disposing of asbestos.

4. State regulations and C&D debris

From the perspective of states having the primary responsibility for C&D debris regulation, Clark *et al.* (2006) provided an extensive review of individual state activities in this regard. They found a high degree of variation among states in regulatory aspects of C&D debris. At a most basic level, states vary in how they define this waste, which affects its management. Some states separately define *construction debris* and *demolition debris*. Some include it in other definitions of waste. For example, Maryland includes C&D debris in its definition of *processed debris*. Mississippi includes C&D debris in its definitions of *rubbish* and *industrial processed debris*. Other states include C&D debris in their definitions of *dry waste* or *inert waste*.

For landfills that accept C&D debris, states also vary in their regulation. California requires that such landfills be located in areas of low seismicity. Indiana specifies characteristics of the soil lining in landfills adjacent to aquifers. Not all states require that landfills have soil liners. Those that do specify a lining system of clay or other soil that meets specific requirements. Some states require leachate collection systems and groundwater monitoring.

Clark *et al.* (2006) effectively documented the wide variation among states in their regulations concerning the disposal of C&D debris. They noted differences with respect to definitions, specifically whether states defined C&D debris as one or two categories for regulatory purposes, whether inert debris was categorized, and if other definitions applied to C&D debris. They noted which states did and did not have landfill liner requirements and which had specifications for leachate collection. Permitting issues they noted were those pertaining to financial assurance and training for operators and landfill spotters. They also reported on state regulations that are specific to C&D landfills and C&D recycling facilities, groundwater monitoring requirements, and which states were updating regulations on C&D debris.

To determine if any state regulations had changed since the Clark *et al.* (2006) study, we contacted appropriate personnel of the landfill-regulating agency in every state and asked if any regulations had changed since that paper was published.

4.1 States that have not updated regulations

States that reported no changes to their C&D debris regulations since the Clark *et al.* (2006) study are shown in Table 1.

State	Notes
Alabama	
Alaska	
Arizona	
Arkansas	
Colorado	
Delaware	
Florida	
Georgia	No changes, but the state has funded a research project to examine the feasibility of more recycling.
Hawaii	No changes to regulations, but corrections should be made to Table 1 in the Clark *et al.* (2006) study: Hawaii does have a definition for construction and demolition waste, but not for construction waste, demolition waste, or inert debris. The state does have other definitions. Hawaii does require spotters, as well as training for spotters, under C&D landfill permits. The state does have regulations covering C&D debris recycling facilities.
Idaho	
Iowa	
Kentucky	No changes have been made, but regulations are currently being revised and will be presented to the state legislature in 2012.
Louisiana	No changes have been made, but the Governor's office issued an emergency declaration on August 30, 2005 to cover the disposal of 22 million tons of debris that resulted from Hurricane Katrina. 600,000 residential structures were affected; of these, 77% were completely destroyed. Over 6,000 commercial structures were affected; of these, 67% were completely destroyed (State of Louisiana, 2005).
Maine	
Maryland	No changes have been made to regulations, but a correction should

	be made to the Clark *et al.* (2006) study to note that the state does regulate C&D landfills and C&D recycling facilities. The study also notes that the state requires a final cover over a landfill of two feet of earth within 60 days and then a cap within two years, but not exactly what the cap consists of: The cap is required to have a low-permeability layer of plastic or clay, a drainage layer, a minimum slope of 4%, and at least 18" of dirt and 6" of topsoil that is compacted and vegetatively stabilized.
Massachusetts	As of July 2011, clean gypsum wallboard will be added to asphalt pavement, brick, concrete, metal, and wood on the list of materials banned from disposal.
Michigan	No changes have been made except generic exemptions for asphalt shingles, new construction drywall, and scrap wood.
Mississippi	
Missouri	
Nevada	
New Hampshire	The discussion about capping systems should be revised to reflect specifications in the New Hampshire Code of Administrative Rules, Part 805.10.
New Jersey	
New Mexico	New Mexico implemented new general solid waste rules in August 2007. Regarding C&D debris, however, no changes have been made.
New York	
North Carolina	Senate Bill 1492 passed in 2007. It has enhanced protections applicable to sanitary landfills, which pertain to C&D debris, that are not in the rules. In particular NEW C&D landfills, of which there are none , and permitted after August 1, 2007, are required to have liners and leachate collection systems. Of particular note is the buffer requirements to parks, wildlife preserves and hunting lands.
Ohio	New rules and programs are currently being adopted, but they are in the early stages. Otherwise, no changes have been made.
Oregon	
Pennsylvania	
Rhode Island	
South Dakota	
Texas	
Utah	
Vermont	
Washington	Most of the information provided in Clark *et al.* (2006) is incorrect or confusing. Washington amended its solid waste rules in 2003, well before that paper was published. State personnel found that the wrong agency had responded to the request for information (WA Dept of Natural Resources) and the wrong regulation was referenced. The current rule no longer includes definitions of demolition or construction waste but has a definition for inert waste as well as standards for inert waste landfills. This is covered in sections 100,

	410, and 990 of WAC 173-350, Solid Waste Handling Standards. Non-inert construction and demolition waste destined for disposal must be managed in either a limited purpose landfill authorized to accept it (Section 400) or at a municipal solid waste (Subtitle D) landfill permitted and operated in accordance with WAC 173-351, *Criteria for municipal solid waste landfills.* These are the only three categories of landfill facilities in the state.
West Virginia	
Wisconsin	
Wyoming	

Table 1. States that have not changed regulations since publication of Clark *et al.* (2006).

4.2 States that have updated regulations

State	Regulation
California	We were unable to find a state official who could give a clear answer on whether regulations had changed. However, Clark *et al.* (2006) cited a definition of inert waste from the California Integrated Waste Management Board as: "Subset of solid waste that does not contain hazardous waste or soluble pollutants at concentrations in excess of applicable water quality objectives, and does not contain significant quantities of decomposable waste." Clark *et al.* (2006), p. 150. We found that the California Integrated Waste Management Board is now the Department of Resources Recycling and Recovery. This definition is provided: "Inert debris means solid waste and recyclable materials that are source separated or separated for reuse and do not contain hazardous waste…or soluble pollutants at concentrations in excess of applicable water quality." Regulations: Title 14, Natural Resources—Division 7, CIWMB. Chapter 3. Minimum Standards for Solid Waste Handling and Disposal, Section 17388. Definitions.
Connecticut	There has been one change to regulations that affect C&D debris since 2005. On May 31, 2006, the state issued the ruling "General Permit for Storage and Processing of Asphalt Roofing Shingle Waste and/or for the Storage and Distribution of Ground Asphalt Aggregate for Beneficial Use." See link: http://www.ct.gov/dep/lib/Permits and Licenses/Waste General Permits/Asphalt roofing shingles gp.pdf
Illinois	New regulations effective in 2009. See link: http://www.epa.state.il.us/land/ccdd/index.html
Indiana	Pulverizing is now banned. Material must be recognizable.
Kansas	Kansas' definition of C&D waste is written to prohibit disposal of

	chemical containers in C&D landfills even if empty. This requirement is why there is no groundwater monitoring. The regulations are available online at the following link: http://www.kdheks.gov/waste/regsstatutes/sw_laws.pdf.. The definition of C&D waste can be found in our state law at the same website at K.S.A. 65-3402(u).
Minnesota	A new rulemaking is underway to address financial assurance and siting requirements. This was initiated at the request of the legislature. The scope of the rule has narrowed to potentially affect only new facilities. The rule revisions were too unwieldy to deal with as one rulemaking and have been split into two: one to address financial assurance and the other to address siting requirements. Current rulemaking can be viewed at this link: http://www.pca.state.mn.us/index.php/waste/waste-permits-and-rules/waste-rulemaking/financial-assurance-and-siting-fasit-rulemaking.html This rulemaking reflects two legislative directives to to improve siting rules to better protect groundwater and improve financial assurance to assure that Minnesota taxpayers are protected, and puts a moratorium on siting or expanding many landfills until such rules are in place.
Montana	New rules for general waste management were issued in February, 2010. Minor changes to wording were included, but no major regulatory changes were made.
Nebraska	Random inspections of incoming loads are required to exclude regulated hazardous wastes or PCB wastes. Personnel must be trained to recognize regulated hazardous wastes and PCB waste. The effective date of Title 132 - Integrated Solid Waste Management Regulations is December 28, 2009. Agency personnel noted the following quotation from Clark *et al.* (2006): "Not only are some discrete components found in buildings hazardous wastes, but the buildings themselves may be hazardous wastes if painted or contaminated with toxic chemicals (e.g., coated with lead-based paint)." Clark *et al.* (2006), p. 144. The department's opinion on that topic is that under the hazardous waste regulations (Title 128) waste determinations are based on the waste "as generated." A demolition then would mean the waste "as generated" is the entire structure. It is not possible for a representative sample of the entire structure to fail a TCLP for metals. The entire mass of the waste versus the small amount of paint in relation to that waste effectively dilutes the results to well below any toxicity characteristic regulatory limits. This is obviously not intentional dilution so it is not affected by the LDR dilution prohibition. There is the remote possibility that a building might have been contaminated with a listed hazardous waste and, as such,

	the entire waste (the building debris) will be a listed hazardous waste under the mixture rule (Title 128, Chapter 2, Section 005.02). It would be possible to do a so-called contained-out determination of the debris if it could be suitably demonstrated the waste contained so little of the listed component that it presents no risk to human health or the environment.
North Dakota	Changes include: Minimize erosion and optimize drainage of precipitation falling on the landfill. The grade of slopes may not be less than three percent, nor more than fifteen percent, unless the applicant or permittee provides justification to show steeper slopes are stable and will not result in long-term surface soil loss in excess of two tons [1.82 metric tons] per acre per year. In no instance may slopes exceed twenty-five percent. Refer to North Dakota Century Code (NDCC), North Dakota Administrative Code (NDAC) Code 33-20-04.1-09 paragraph 4b3.
Oklahoma	Changes became effective July 11, 2010 and included the amendment of certain rules that directly affect C&D facilities. These changes include the following: 1. OAC 252:515, Subchapter 15: The exemption for C&D landfills was removed. This means that C&D landfills will be required to implement methane gas monitoring and control which includes the installation of gas probes, the submittal of an explosive gas monitoring and analysis plan to DEQ, and procedures for corrective action if explosive gas levels are exceeded. 2. OAC 252:515, Subchapter 29: The exception for C&D landfills was removed. This means that C&D landfills are required to have a waste exclusion plan (WEP). The key dates for implementing these rule changes are as follows. 1. OAC 252:515, Subchapter 15: a. An explosive gas monitoring and analysis plan (Plan), as required in OAC 252:515-15-3(a), must be submitted to the DEQ for approval no later than January 7, 2011. b.The Plan must be implemented no later than 90 days after it is approved by the DEQ. 2. OAC 252:515, Subchapter 29: a. A WEP, as required by OAC 252:515-29-2(a), must be submitted to the DEQ for approval no later than January 7, 2011.
South Carolina	New regulations went into effect in 05/2008. No major changes to requirements but some terminology changes – see http://www.scdhec.gov/environment/lwm/html/solidwaste_new_regulation.htm Regulation Code: 61-107.19.
Tennessee	All landfills are now to have groundwater monitoring. Cover frequency used to be less frequent, but is now once per week.
Virginia	Virginia Solid Waste Management Regulation, 9VAC20, Chapter 81 to be posted to the Virginia Department of Environmental Quality

	website as of March 16, 2011. Inert waste is no longer defined in the regulation, and the definition of C&D landfill has changed: "Construction/demolition/debris landfill" or "CDD landfill" means a land burial facility engineered, constructed and operated to contain and isolate construction waste, demolition waste, debris waste, split tires, and white goods, or combinations of the above solid wastes. Leachate control and monitoring are required. Gas management is required unless the operator can demonstrate that gas formation is not a concern.

Table 2. States that have changed regulations since publication of Clark *et al.* (2006).

Tables 1 and 2 demonstrate the difficulties associated with presenting a clear picture of the issue of C&D debris management across the United States. Some states have detailed definitions and management policies for C&D debris and the facilities that handle it. Specifications for landfill liners and covers vary, as do requirements for leachate management. Problematic issues related to gypsum wallboard waste are highlighted by the ban on disposal of this waste by Massachusetts. And as can be seen in the case of Washington, despite their meticulous research approach, Clark *et al.* (2006) were misled by a staff person in a state agency who thought his agency had regulatory authority over C&D debris when it did not.

Among other issues, the management of C&D debris has implications for water and air quality. A state with minimal oversight of such debris can affect the quality of air and water in adjacent states. Policy implications of this situation may include regional cooperation among states in their management of C&D debris, at a minimum. In addition, policies need to be communicated clearly so that those involved in construction, demolition, and related industries can remain in compliance in ways that do not have negative impacts on housing affordability and other issues.

5. Local municipal programs

Many local governments have instituted programs and issued regulations as a method to reduce the amount of C&D waste flowing to local landfills. Three examples of specific local programs are described below.

The city of Portland Oregon provides an example of a local municipality that has set regulations that require the general contractor of all building projects costing over $50,000 to make certain that 75% of the waste produced on the job-site be recycled. The general contractor is responsible for setting up a recycling program, including containers or storage areas separate from garbage for materials being recycled. The general contractor must complete a pre-construction recycling plan that details precisely how/where the following materials will be recycled:

- Rubble (concrete and asphalt)
- Land clearing debris
- Corrugated cardboard
- Metals
- Wood (City of Portland, Oregon, 2011).

The City of Austin, Texas provides an example of a municipality that uses a green building program to provide incentives to reduce construction wastes. The program sets minimum recycling and/or reuse levels of construction waste if buildings are to qualify for the Austin Energy Green Building designation. Waste reduction and recycling requirements set forth in program are designed to assist the city in meeting a waste reduction goal that calls for a 90% reduction in materials sent to landfill by 2040 (Austin Energy, 2010).

As part of the requirements that builders and developers must meet to obtain the Austin Energy Green Building designation, they must set aside space on the construction site for sorting and temporary storage of reusable/recyclable materials. Builders are allowed to reuse many of the waste materials on-site. For example, waste wood and cleared brush can be chipped and used for on-site landscaping purposes. Gypsum drywall scraps can be ground on site and used as a soil amendment. Concrete can be crushed and used as fill or drainage under garden beds or driveway areas. The program requires that a minimum of 50% of the waste generated by the construction project must be recycled or reused (Austin Energy, 2010).

The city of Seattle has also set very ambitious targets for reducing waste materials. The city has set a goal to reach a 70% recycling target by 2025. As a method to reduce construction waste, the city provides educational materials to contractors and developers on methods to reduce construction waste. They have an on-line checklist that describes basic steps in setting up a job-site reuse and recycling strategy. In addition, the following on-line resources are also provided: (1) A searchable data base for recycling construction and demolition waste, and (2) A recycling directory to identify what materials are easiest to recycle in the region (City of Seattle, n.d.).

6. Green building programs and C&D debris

Besides regulation, incentives exist for managing C&D debris in ways other than disposal in landfills. A number of green building programs are now in effect at the national, state, and local levels throughout the U.S. The most well-known of these is Leadership in Energy and Environmental Design (LEED), which is administered by the U.S. Green Building Council (USGBC). LEED is a program through which buildings are certified as meeting sustainability standards. LEED focuses on specific areas environmental health, including resource efficiency. Points are awarded to a development project for minimizing the amount of C&D debris that is sent to landfills. LEED is applicable to all buildings, including homes.

Since 2004 Enterprise Community Partners has administered the only national program to develop green homes for low-income families. The Green Communities Criteria established under this initiative relate to design, neighborhood fabric, resource efficiency, environmental health, and maintenance. This program features green characteristics that are found in many LEED buildings, but differs in its focus on serving low-income families. This effort also has a focus on minimization of C&D debris that is sent to landfills.

With input from several thousand stakeholders, the National Association of Home Builders (NAHB), the International Code Council (ICC), and the NAHB Research Center developed ICC-700, the National Green Building Standard. It was approved in 2009 as an American National Standard, and is the only green standard that is consistent with ICC's I-Codes. Green features covered by this standard are similar to those in use by LEED and Enterprise. ICC Codes are used as the basis of building codes in use across the United States.

The EPA Indoor airPlus program of the U.S. Environmental Protection Agency is an enhancement to the ENERGY STAR Home program. ENERGY STAR homes are certified to

perform to a level of energy efficiency that is typically 20 – 30 percent higher than conventional homes. To be certified as an Indoor airPlus home, over 30 additional construction features are added to the home, including resource efficiency.
An implication of more widespread adoption of green building programs would be an increased awareness of the amount of construction debris that can be diverted from landfills. And as green buildings are planned in advance for deconstruction, less demolition debris will be produced.

7. The issue of gypsum

One issue that has posed challenges to C&D recycling is that of gypsum wallboard waste. This wallboard is comprised of gypsum with paper facing and backing. Gypsum is calcium sulfate dihydrate, a mineral that is mined from dried sea beds. It is the most common interior wall finish material used in new construction and remodeling in the United States (CalRecycle, 2007).
Gypsum board, also widely known as drywall or mistakenly as the brand name of a U.S. Gypsum Corporation product, Sheetrock®, generally makes up the largest single component in the C&D construction waste stream. A Cornell University study found that, on average, some 1,700 pounds of gypsum waste is produced per home constructed, amounting to approximately one pound per square foot of house area (Laquatra and Pierce, 2004).
The usual method of finishing drywall, the use of tape and joint compound to cover joints and screw depressions, is most efficiently done when the largest possible pieces of drywall are used to reduce the number of joints. This in turn requires cutting openings for doorways, windows, heating/air conditioning vents, electric receptacle and switch boxes, and junction boxes for light fixtures (as opposed to piecing multiple drywall sheets together to form openings). This produces the bulk of construction drywall waste.
Management of drywall waste may involve either disposal or recycling. Frequently, drywall waste is disposed of by simply dumping it in landfills. The chemical composition of the gypsum used in drywall, however, presents at least one important obstacle to disposing of such waste in this manner.
Many landfills in the United States now recover and use the methane gas produced by decomposition of buried organic waste. Sulfate-reducing bacteria, which thrive in the anaerobic conditions of landfills, produce hydrogen sulfide gas as they break down the sulfites in gypsum. Hydrogen sulfide gas has a foul odor and can make people sick. It is lethal in high concentrations. In addition, the presence of this hydrogen sulfide in methane recovered from landfills reduces the quality of the methane gas. Although technology is available to lessen the amount of hydrogen sulfide in recovered methane, the added expense of doing so prevents many landfills from accepting drywall waste.
One suggested method of drywall disposal is to cut scraps into small pieces and then place them in the uninsulated cavities of interior partitions (Yost, 1997). This technique has yet to be widely used, in part because of the additional labor required.
As an alternative to simply disposing of drywall waste, recycling technology has advanced to the stage where builders are now able to separate gypsum from other waste materials onsite to be picked up by drywall recyclers at costs comparable to those of landfill disposal.
Recycled gypsum from residential construction waste is used in the manufacturing of new drywall, the making of cement, as filler in stucco, as a precipitant to remove solids from turbid water, and as an absorbent to dewater the resulting sludge, in the treatment of waste

water, and in the production of cat litter. Another disposal option is the reduction of waste gypsum to a powder, which because of its alkalinity, may be used in agriculture to increase the pH of overly-acidic soil. Some states, however, do not permit this.

Green building programs are now having an impact on drywall recycling. For example, USA Gypsum of Lancaster, Pennsylvania reports that much of the demand for their waste gypsum collection and recycling services is driven by requirements of green building programs (Weaver, 2011). One of the most widely known green building designation programs is LEED, which was developed by the United States Green Building Council to provide third-party verification that a building is designed and constructed to meet strict environmental criteria (USBC, 2008). One of the requirements of this certification program is that a certain percentage of the waste materials generated during construction, including gypsum, be recycled.

Even in relatively remote areas of northern NY, several hundred miles from USA Gypsum processing facilities in Pennsylvania, building contractors are willing to pay the additional costs for collection, transportation, and fees to accept the scrap gypsum for recycling if it is required to obtain the green certification for the building they are constructing (Weaver, 2011).

While the increased demand for gypsum waste recycling created by green building programs is a positive step toward reducing the amount of gypsum being land filled, there are several factors creating significant barriers to more widespread recycling of waste gypsum board. None of these factors is more significant than the movement of gypsum wall board manufactures to begin using synthetic gypsum as the preferred input to produce new wallboard. Synthetic gypsum is formed as a by-product of the process used to remove sulfur dioxide from exhaust flue gasses of coal-fired electric plants. Synthetic gypsum and naturally occurring gypsum ore are virtually chemically identical. Older gypsum board plants were capable of using a percentage of synthetic gypsum mixed in with pure natural ore. But newly constructed gypsum board plants have been designed to produce wall board without using any natural gypsum ore (U.S. Gypsum Association, 2008).

While these modern plants also have an increased capacity to accept ground gypsum processed from recycled gypsum wallboard scraps, it is currently not economically possible for gypsum board recycling firms such as USA Gypsum to compete with synthetic gypsum (Weaver, 2011). Wallboard manufacturers typically receive synthetic gypsum at no cost from coal fired electric plants. The only expense to the board manufacturing plant is the cost of transportation to get the synthetic gypsum from the power plant to the board manufacturing facility. In some cases gypsum wallboard manufacturers are building production facilities right next to coal fired electric plants as a method to minimize transportation costs.

The use of a waste product produced by one industry, the coal fired electric industry, as a raw material input for a different industry, the gypsum board manufacturing industry, is definitely a sign of progress toward moving from a linear system of resource consumption to that of a circular system where waste products of one firm serve as material inputs for another. But we are still left with the issue of how to divert millions of tons of gypsum wallboard scrap created by the construction industry from the nation's landfills. As noted earlier, decomposing gypsum in landfills produces foul smelling hydrogen sulfide gas that can create health and air quality issues for residents living miles away from the landfill. In addition, the presence of hydrogen sulfide gas reduces the quality of the methane gas recovered from the landfill. Because of these issues many local legislators and state environmental departments across the country are considering increasing tip fees for scrap gypsum or banning it from landfills altogether and requiring recycling of scrap gypsum (Breslin, 2010). These steps would create incentives to increase recycling of scrap gypsum generated by the building construction industry.

8. Waste avoidance

The growing complexity of issues related to C&D debris highlight the importance of adopting practices that minimize its production. Green building programs provide examples of incentives available to builders and remodelers for reducing the amount of debris sent to landfills. Ikuma *et al.* (in press) discuss *lean construction* as a means for using building materials efficiently, through adoption of modular building methods and increased use of factory-built panels. They presented case studies that showed a 64% reduction in material waste through adoption of the technique.

Another method for reducing the amount of C&D debris produced at a construction site involves the use of *advanced framing*. This term refers to a building technique that reduces the amount of lumber used in wood-framed houses in a way that does not sacrifice stability of the structure. Vertical framing members (studs) are aligned with those placed horizontally (joists) or at an angle (rafters). Supporting members over doors and windows (headers) are sized in a way that eliminates the need for excess wood that is commonly used. Corners are framed in ways that use wood more efficiently and allow for more insulation than is possible with conventional, overbuilt corners (NAHB Research Center, 2008).

9. Conclusions and implications

Human civilization has come full circle in its dealings with management of waste. Early humans were careful with things they produced. They reused them, and then repaired them when they broke. This was common practice until the Industrial Revolution, which made materials commonly available. Coal-fired equipment provided the ability for the production of large amounts of inexpensive goods, which then led to increasing amounts of waste (Waste Online, 2004). This same pattern was observed in the construction industry, which evolved from careful reuse of timbers for ships and buildings to sending demolition debris and construction waste to landfills. C&D debris was initially considered to be environmentally benign, but that perception gradually changed with a growing focus on hazardous components of this debris, including lead and other heavy metals, asbestos, arsenic, polychlorinated biphenyls, and others (Clark *et al.*, 2006).

Until the early 1990s, C&D debris was routinely sent to landfills, with little attention given to recycling or reuse options (Goldstein, 2006). While early landfills were essentially holes in the ground, modern landfills are now lined with compacted clay, high density polyethylene (HDPE), or other materials. None of these lining materials provides a layer that can be considered as impermeable indefinitely. Compacted clay can crack, synthetic fibers can leak, and landfill vents have been observed to release high levels of toxins (NEWMOA, 2010). C&D debris that has been deposited in either lined or unlined landfills is cause for concerns related to environmental contamination.

While the 170 million tons of C&D debris produced annually in the United States is managed considerably better now than it has been in the past, this chapter has shown where improvements can be made. The amount of this debris that is produced, for example, can be substantially reduced by producing less of it, through techniques known as lean construction and advanced framing. Efficiency improvements in the construction process will lead to less waste in construction materials and debris that is sent to landfills. Green building programs are expanding awareness of recycling and reuse options and may have substantial impacts on the reduction of C&D debris produced as those programs move further into the mainstream.

Government efforts at all levels – federal, state, and local – need to demonstrate a higher level of awareness of issues related to C&D debris. While the federal government has mostly left management of C&D debris to the states, the wide variation among states in this management shows that some states take on a strong management role to prevent pollution of groundwater and air, while others provide minimal oversight. And the case of Washington demonstrated that state agency personnel are not always aware of which agency has oversight responsibility. But these are issues that may be handled well at the local level, as our discussion of local government actions by Portland, Austin, and Seattle demonstrated.

Some building materials, most notably gypsum wallboard, may receive more attention in the coming years. Once regarded as a benign waste material, its role with gas production in landfills is receiving more notice, as is seen with the ban on its disposal in Massachusetts.

While regulation of C&D debris varies throughout the United States, an educational approach designed for those involved in all phases of its life cycle, from production to disposal or reuse, would be beneficial. Builders could participate more widely in green building programs; and purchasers, managers, and occupants of all types of buildings could become more aware of these programs and exert demand-side pressure for supply side participation. Those involved in all aspects of the building industry, from the creation of a structure until its demise, need to assume greater responsibility for improved management of C&D debris in the United States.

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This book reports research on policy and legal issues, anaerobic digestion of solid waste under processing aspects, industrial waste, application of GIS and LCA in waste management, and a couple of research papers relating to leachate and odour management.