Investigation of Disposal and Recovery of Wood and Wood Packaging in the United States

Zachary P. Shiner

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Laszlo Horvath, Chair
Robert Smith
Philip Araman
Robert Bush

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Abstract

Each year a large number of wooden pallets are manufactured, recycled, and disposed of during the transportation of goods throughout the United States. The production of these pallets consumes a significant amount of wood, a large number of pallets also end up in landfills at the end of their useful life. However, these pallets can be recovered through repair, separated into components, ground into mulch, fuel, animal bedding, or used by landfills as cover or road base in day to day operations. The purpose of this research was to investigate the total number of pallets reaching landfills in the United States as well as to gain a better understanding of the overall waste stream. This was done by surveying all licensed Municipal Solid Waste (MSW) and Construction & Demolition (C&D) landfills in the continental United States. A questionnaire was sent to these landfills, and this entire study was intended to build upon previous Virginia Tech landfill surveys conducted in 1995 and 1998.

Overall, it was found the average MSW facility in the United States received 185,077 tons of waste per year and the average C&D facility received 74,911 tons. This results in a total national estimate of 253 million tons of MSW and 76.9 million tons of C&D waste. Approximately 18.3 million pallets were landfilled and an additional 13.8 million were recovered, repurposed, or reused at MSW facilities. At C&D facilities, approximately 19.2 million pallets were landfilled while 38.3 million were recovered.

The production, use, and disposal of pallets has a major impact on the economic and industrial conditions of the United States. Pallets have a critical role in facilitating the unitization of goods across the global supply chain. By gaining a better understanding of the waste stream of pallets, it can promote recovery and discourage disposal as landfills and businesses learn more about the potential value of broken or discarded pallets. Pallet recycling generates economic activity, reduces the amount of natural resources extracted, and also conserves limited landfill space.

General Audience Abstract

Millions of wooden pallets are involved in the transportation of goods each year and have a major role in the global distribution system. The production of these pallets consumes large volumes of wood that may end up in landfills when their life cycles have been completed. Generally, wood is a desirable natural resource and landfilling is the least desirable method of waste management. However, pallets can be recovered through repair, broken apart into components, or ground into mulch, fuel, animal bedding, or used by landfills for day to day operations. The purpose of this research was to investigate the total number of pallets and crates reaching pallets in the United States as well as to gain a better understanding of the overall waste stream. This was done by surveying over 2500 licensed Municipal Solid Waste (MSW) and Construction & Demolition (C&D) landfills in the continental United States through mail questionnaire with an option to be completed online.

Overall, it was found the average MSW facility in the United States received 185,077 tons of waste per year and the average C&D facility received 74,911 tons. This results in a total national estimate of 253 million tons of MSW and 76.9 million tons of C&D waste. Approximately 18.3 million pallets were landfilled and an additional 13.8 million were recovered, repurposed, or reused at MSW facilities. At C&D facilities, approximately 19.2 million pallets were landfilled while 38.3 million were recovered. This represents a decrease in the number of pallets landfilled and an increase in the number recovered when compared to the surveys conducted in 1995 and 1998 by Corr et al.

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Literature Review

1.1 Introduction

Wood is one of the most versatile, renewable, natural resources on earth. Its ease of craftsmanship, strength, aesthetically pleasing appearance, and wide geographic availability have made wood desirable for a wide range of applications. The growth of wood in forests and on plantations provide essential benefits to the biosphere. Mankind's relationship to this resource dates back to prehistoric times. Researchers have found wooden spears from the Paleolithic site Schoningen dating back over 300,000 years (Schoch *et al.*, 2015). To this day, woody biomass is one of the most important renewable sources of energy, fueling over half of Europe's renewable-energy consumption in 2013 (*The fuel of the future: Environmental Lunacy in Europe*, 2013). With mankind's discoveries in industrial processing and chemistry, wood and its chemical derivatives can now be used in the creation of plastics, chemical feedstocks, liquid and gaseous fuels, food supplements, and 14,000 kinds of paper (Council, 1972).

Trees grow through the biological process of photosynthesis, which converts light into chemical energy, and through the transformation of water and carbon dioxide into glucose and oxygen, and that can later be used by the tree to fuel its cellular functions. With increasing concerns about climate change, it is important to recognize how large of a role forests play in reducing atmospheric carbon dioxide. Every cubic meter of wood stores approximately 1 ton (2,204.6 lbs.) of carbon dioxide, so an 80 foot hardwood tree with a 24" diameter which can weigh more than 20,000 pounds, is storing approximately 10 tons of carbon dioxide (Chameides, 2007). A 2011 study by the University of Leeds found that global forests "absorb more than 40% of the 38 billion tons of carbon dioxide created by mankind every year (Gray, 2011)." Additionally, whenever wood is used in the manufacturing of products or building construction, carbon is stored until the wood decomposes or is combusted. As Liisa Rohweder of WWF Finland stated, "a hugely beneficial aspect of wood construction is that each cubic meter of wood used contains about one ton (2,204.6 pounds) of carbon dioxide that has been extracted out of the atmosphere by the tree. The longer the building is in use, the longer the carbon stays out of the atmosphere ("Construction Is the Best Use of Wood" 2017)."

There are over 100 species of trees in the United States and many more throughout the world (Service, 2010). Because of varying anatomical cellular features and different chemical composition in the various species of wood, its strength properties, appearance, resistance to penetration by water and chemicals, resistance to decay, pulp quality, and its chemical reactivity differs significantly between species. This creates different end uses and markets depending on demand and availability (Durbak *et al.*, 2000). The two broadest classifications of trees are hardwoods and softwoods.

Common types of softwoods include Spruce, Pine, Cypress, Fir, Cedar, Larch, and Hemlock (*Species and Characteristics*, 2017). They are gymnosperms which means they have uncovered seeds and cones which pollenate openly, and coniferous which means they produce cones or fruits with needles or scale-like leaves which are not shed `with the changing of the seasons. Softwoods are porous and do not contain vessel elements. Many softwood species grow faster than hardwoods, and their wood is typically less dense because the cells have more space between them. "Wood density is determined largely by the relative thickness of the cell wall and by the proportions of thick-walled and thin-walled cells present (Durba 1998a)." The cells that make up softwoods are arranged in straight, radial rows with longer fibers than hardwoods. These long fibers help create the strong cellulosic bonds that are desirable in manufacturing paperboard packaging. This uniformity in cellular structure also provides reliable performance in building strength and construction, allowing for nailing with less splitting than hardwoods ("What is the difference between hardwood and softwood?," 2017).

Hardwoods are angiosperms, or plants with covered seeds, with broad deciduous leaves that shed with the seasons. Hardwoods are porous, and this leads to more varied anatomical features than softwoods. Hardwoods have vessels and a lack of uniformity in their cellular arrangement. There are many more species of hardwoods than softwoods throughout the world. Common species in North America include maple, ash, oak, poplar, and cherry. Hardwoods usually have more density than softwoods. This gives hardwoods stronger mechanical performance characteristics because density is strongly correlated with bending, crushing strength, and hardness (Durbak *et al.*, 2000). Denser wood also provides higher energy output when combusted on a per cord basis. High quality hardwoods are valued for many applications including furniture, instruments, shipbuilding, milling, flooring, tool making, and sporting equipment (*Things we make from hardwood trees*, 2017).

Due to overharvesting, some exotic species of hardwoods (such as the Brazilian Rosewood or Spanish Cedar) have been added to an intergovernmental treaty formed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). This limits the trade of exotic wood to that which was exported before the

CITES ban, or that has fallen naturally (Hunter, 2016). Other organizations also attempt to maintain standards regarding forest management, fiber sourcing, and records of chain-of-custody provenance. The largest international forest certification programs are the Programme for the Endorsement of Forest Certification (PEFC), which has approximately 770 million acres of certified forests, and the Forest Stewardship Council (FSC) which has just 170 million acres of certified land in the USA and Canada.

1.2 Forest Products Industry

Globally, the five largest producers of sawnwood (lumber) are the USA, China, Canada, the Russian Federation, and Germany. China and the USA were the world's largest consumers of sawnwood in 2014, consuming 40.25 BBF (billion board feet) and 38.1 BBF, respectively (FAO, 2014). Of the 38.1 BBF of sawnwood that the US consumes, roughly 8 BBF is from hardwoods, and the other 30 BBF is from softwoods (Johnson & Caldwell, 2014) (Bumgardner, Johnson, Luppold, Maplesden, & Pepke, 2014). The forest products industry accounts for approximately 4% of the total U.S. manufacturing GDP. It creates over $200 billion in products annually and employs approximately 900,000 people. It is also among the top 10 manufacturing sector employers in 45 states (Matthis, 2017). Approximately 11 million private landowners in the U.S. manage close to 640 million acres of family-owned timberlands.

In the United States, more than half of the wood harvested from forests end up as building materials used in construction (*Wood Handbook*, 2010). In 2006, there were approximately 1.9 million housing starts with the average residential unit requiring 14,800 bf (board feet) of lumber, 10,600 ft^2 (3/8-inch basis) of nonstructural panels, and 1,400 ft^2 (3/8-in basis) of structural panels (Adair and McKeever, 2006). Wood has many positive characteristics that make it a good choice to be used in construction including low embodied energy, low carbon impact, and sustainability. Additionally, advances in wood technology, such as the creation of cross laminated timbers (CLTs), have allowed architects to design wooden buildings much taller than previously thought possible. The Chicago based architecture firm 'Skidmore, Owings & Merrill' recently published a feasibility study for a 42-story building made predominantly of CLTs (Risen, 2014). Using wood as an alternative to steel or concrete can result in many benefits. Wood construction sites generate less waste, noise, and traffic than steel building construction sites (Deaton, 2016). A 2014 study from researchers at Yale and the University of Washington found that as much as 31 percent of global carbon dioxide emissions could be avoided by building with wood instead of steel and concrete (Deaton, 2016).

1.3 Wood Fiber Based Packaging Market

The largest, domestic, non-fuel use of wood fiber is in the packaging and palletization of consumer and industrial products (White and Hamner 2005). Low grade hardwood and softwood lumber is used in the production of various wood packaging items such as pallets, crates, and corrugated boxes. The production of corrugated boxes, which can be moved about on pallets, consume significant amounts of wood fiber as they transport goods between shipping points along the global supply chain. Corrugated containers allow for standardization and efficiency at a low cost with high manufacturing speeds and ease of disposal at the end point. Corrugated containers have become the backbone of the modern global supply chain with approximately 80% of all goods being transported using them (Twede, Selke and Kamden, 2014). In 2014, the United Nations Food and Health Organization (UNFAO) reported that the United States produced 46 million metric tons (MT) of packaging made from the total of 73 MT pulp and paper produced (FAO, 2014). The corrugated container industry has found a new area for growth with the popularity of e-commerce (i.e. direct to home), and corrugated and paperboard production rose 7.2% from 2015 to 2016 (Matthis, 2017). The production of paper and paperboard (including paper bags and cartons) is the largest sector in the packaging industry, with a 34% share of a market valued at $500 billion USD. (Young, 2016)

Each year new over 500 million pallets are manufactured using approximately 40 percent of all hardwood lumber produced in the United States (Figure 1), which totaled 22 million m^3 in 2016 (Annual Market Review, 2016).

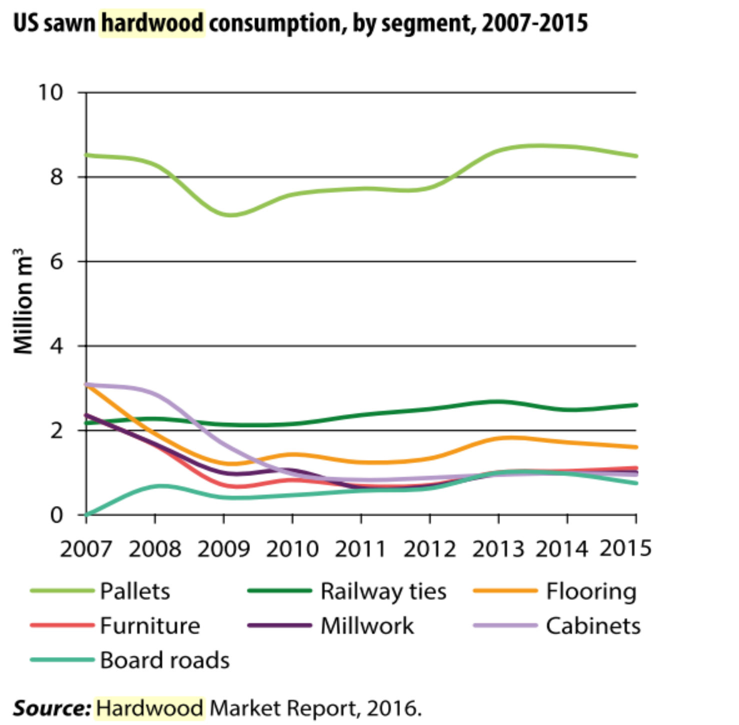

Figure 1 US Hardwood Consumption by Year (UNECE 2014).

Under the North American Industry Classification System (NAICS), Wood Container and Pallet Manufacturing (NAICS 321920) is comprised of establishments which focus on the production of wood pallets, wood boxes, other wood containers, and wood parts for pallets and containers (*NAICS Class Codes*, 2016). The Wood Container and Pallet Manufacturing industry is generally considered a subsidiary of Wood Products Manufacturing (NAICS 321). The Wood Products Manufacturing sector incudes the manufacturing of products such as lumber, veneer, wood containers, wood flooring, wood trusses, manufactured homes (*Industries at a Glance: Wood Product Manufacturing*, 2017). Table 1 shows Statistics of U.S. Businesses from the U.S. Census Bureau created over the past five years. The total shipments and receipts of the Pallet and Container industry account for approximately 9% of all wood products shipments and receipts.

Total employment by the pallet and container industry has remained relatively consistent during a period when employment throughout the rest of the wood products industry decreased significantly. From 2008 to 2015, employment by the Pallet and Container industry only decreased by 6.75% while employment in the wood products industry as whole decreased by 23.76% (Table 2). In 2007, it was estimated that there were over 2,948 establishments making pallets and containers in the United States.

Table 1 North American Industrial Classification System (NACIS) Total value of shipments and receipts for codes 321: Wood products and 321920: Pallet and container industry from 2010 to 2015, from the US Census Bureau's Annual survey of Manufactures. (*) Denotes that data was not available for 2012 since it was a census year (Census Buerau, 2017).

	Value of Shipments and Receipts (Thousand $US/Year)					
Industry Sector	**2010**	**2011**	**2012***	**2013**	**2014**	**2015**
NAICS 321920: Wood Containers and Pallets	6,177,713	6,529,965		7,216,118	8,271,281	9,153,569
NAICS 321: Wood Products	69,389,352	69,846,156		88,560,941	94,924,481	97,193,475
NAICS 321920: (% Share)	8.90	9.35		8.15	8.71	9.42

Table 2 NAICS Employment data for industry codes 321: Wood products, and 321920: Pallet and Containers (Census Buerau, 2017) (*) Denotes that data was not available in 2012 since it was a census year

	Total Employment by Sector		
Year	321920: Pallets and Containers	321:Wood Products	321920: Share (%)
2008	56,643	465,412	12.17
2009	48,150	356,470	13.51
2010	46,489	336,526	13.81
2011	48,551	324,870	14.94
2012*			
2013	48,729	345,846	14.09
2014	51,345	352,084	14.58
2015	52,945	366,584	14.44

In 2016, Gerber et al. estimated that the United States produces approximately 500 million new pallets every year (Gerber 2016). Previous research indicated that there are 2 billion pallets in use at any given time. This means that the pallet stock is replenished every four to five years due to breakdown during use (Buehlmann et al 2009) . It is estimated that 90-95% of pallets are made from wood (White and Hamner, 2005). Pallets also have a high rate of recovery, and the market for recycled pallets has grown significantly over the past few decades. The number of recovered, repaired, or remanufactured wooden pallets increased from 143 million in 1995 to 235 million in 2016 (Gerber and Horvath, 2016). Based upon the estimates for new pallets produced and recycled pallets entering the market, the total demand for pallets has risen to approximately 770 million a year in the United States alone. These numbers are supported by a

2014 report from Howe and Bratkovich, which estimated that 75% of pallets are reused. This indicates that more than a quarter of the estimated 2 billion pallets in use need to be replaced every year. Noticing an increase in the demand for recycled pallets, Bush, Araman, and Hagar gave several possible explanations in a 1995 article. These included:

- "Increased awareness of the environment and activities that affect the environment have caused a previously unconcerned public to question the use of new wood for pallets;
- Pallet producers, concerned with the availability and price of new lumber and cants, have found it economically advantageous to repair pallets and salvage materials from used pallets;
- Pallets users have turned to recycled pallets as a way of decreasing their product handling costs;
- Pallet disposal costs can be significant and increasing attention is being paid to reduce or avoid these costs through recovery and recycling;
- Barriers to entry into pallets recycling are relatively low, resulting in an increase in the number of pallet recovery and recycling only firms (I.e. firms that do not manufacture new pallets); and
- Public concerns over the capacity and cost of landfills have resulted in laws banning pallets in some facilities (Araman, Bush, Hager 1995)."

According to waste characterization data from the US Environmental Protection Agency, wood made up 8.1% of all municipal solid waste (MSW) landfilled in US throughout 2014 (United States Environmental Protection Agency, 2015). Previous research estimated that 2-3% of this wood waste consists of pallets (Corr 1998). In 2014, the EPA reported that wood packaging made up 3.7% of the 76 million tons of total packaging waste generated (United States Environmental Protection Agency, 2015). This represents a potential source of recoverable materials that could be managed put to more effective than being buried in a landfill cell. It also may help the pallet recycling industry, which has seen a shortage of new pallets available to replenish the market (Angellotti and Pallet, 2015). The economic downturn of 2008 led many companies to switch to purchasing more recycled pallets instead of new pallets as a way to reduce costs. This, combined with Costco's decision in January of 2011 to switch to CHEP pool pallets, has continued to reduce the market's supply. By diverting pallets from the landfill, it is more likely that they could end up back in use in the pallet market.

1.3 Pallet Basics

In the broadest sense, a pallet is defined as a "horizontal, rigid, composite platform used as base for assembling, storing, stacking, handling, and transporting goods as unit load; often equipped with a superstructure (MH1, 2016)." Typically, pallets are designed to be used in conjunction with material handling equipment such as forklifts, manual or power operated handtrucks, or conveyors, and they are often stored in rack systems. As shown in Table 2, Wood Pallets and Containers (NAICS 321920) made up 9.42% all shipments and receipts in the Wood Products industry (NAICS 321) in 2015. Although pallets can be made out of metal, plastics, corrugated paperboard, or a variety of composites, wood is by far the most commonly used material (White and Hamner, 2005). Widespread regional availability and rugged performance, along with ease of manufacturing and repair, make wood the ideal material for pallets.

Pallets form the foundation of the unit load, which is the basis for global transportation. "A unit load is a single item, a number of items, or a bulk material that is arranged and restrained so that the load can be stored, picked up, and moved between two locations as a single mass (White and Hamner, 2005)." Using pallets, unit loads can be easily floor-stacked on a warehouse floor, stored in many types of warehouse rack systems, and transported by truck, airplane, ship, or rail between any facilities which have forklifts or pallet handtrucks. While nearly anything that doesn't have exceptionally large dimensions can be palletized, 93-95% of all unit loads have a pallet beneath them, and approximately 95% of all goods are shipped in corrugated boxes (Buehlmann, Bumgardner and Fluharty, 2009) (White and Hamner, 2005) (Batelka and Smith, 1993). Thus the majority of the two billion unit loads in transit every day in the United States are likely comprised of corrugated boxes stacked upon wooden pallets. While there are alternatives to palletized unit loads, such as slip sheets or clamping, these methods require relatively specialized equipment.

Of all of the materials used to create pallets, wood has the largest share of the market with just over 90% (Trebilcock, 2013) (Anthony, 2013). Several factors contribute to wood's favorability in pallet manufacturing. Low material and production costs along with the availability and flexibility of the materials makes wood a good choice for producers (Buehlmann, Bumgardner and Fluharty, 2009). Using wood for pallet construction allows for a broad choice of design options including overall dimensions, species used, number of stringers and deckboards, deckboard width and thickness, height and width of stringer, and deckboard spacing. Common species of wood used in pallet construction include oak, maple, mixed hardwood, SPF, Douglas-Fir, and Southern Pine, among others (Bush and Araman, 2008). High strength, stiffness, weight, durability, functionality, and low price make wood the ideal material for pallet users (Clark 2004). However, wood pallets are not without their drawbacks. They can harbor pests, splinter, give off moisture, and exposed fasteners can cause product damage (Clark 2004).

Pallets provide several benefits to material handling systems, the most important of these being standardization, efficiency, and product protection. “Pallets are almost universally adaptable to a variety of handling situations and locations; and in addition to providing a product platform, the pallet is a buffer against the handling environment” (Soroka, 2009). The ability of material handling equipment to access and handle pallets can have significant implications for logistical operations. This must be carefully considered in order to match production processes, warehouse spaces, and available equipment. In general, pallets are highly standardized which optimizes the supply chain and prevents product damage while helping to avoid safety related incidents.

The needs of users have led to the development of two main classes of wooden pallets: block and stringer. Research into pallet repair and manufacturing by Bejune et al of Virginia Tech estimated that the market is comprised of 80% stringer pallets and 20% block pallets (Bejune, 2001). The most common stringer pallet is known as a 48”x 40” GMA (Grocers’ Manufacturers Association) design. This was an attempt to standardize pallets for users and producers in the 1960’s and 70’s (Figure 2a) (Angellotti and Pallet, 2015) (Corinne Kator, 2016). The GMA stringer pallet is partially accessible on all sides with a double-faced, non-reversible design. This means that the pallet has a designated stacking surface, and this orientation should be maintained throughout the pallet’s use in the supply chain. These differing designs allow for variations in cost and performance depending upon the needs of the user.

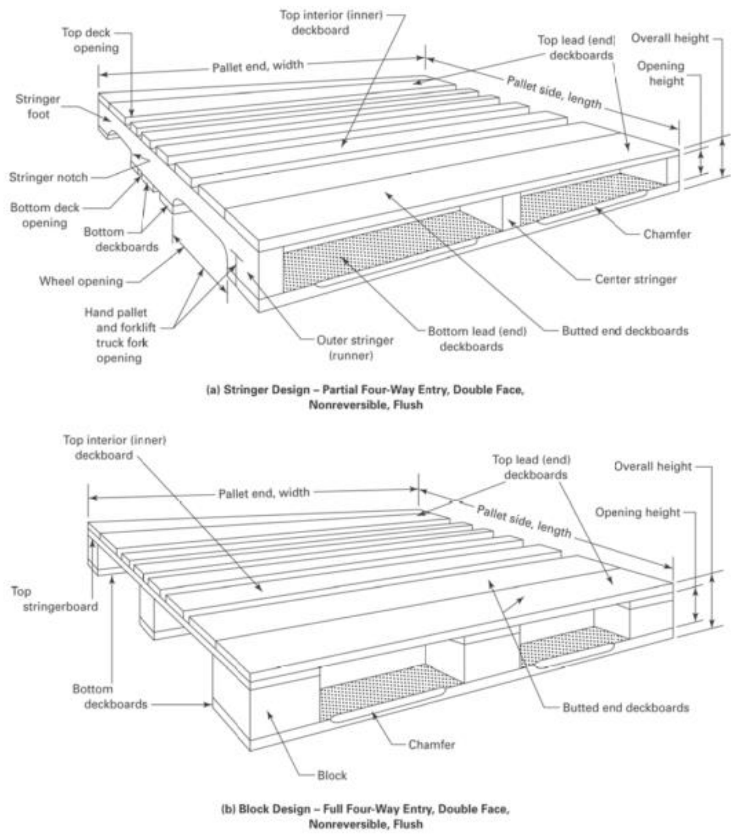

Figure 2 Illustrations and labeled components of a GMA stringer pallet (a) and block pallets (b) (MH1, 2016)

Alternatively, a pallet can have full, four-way design access meaning that both forklifts and pallet handtrucks can access it from all sides. This feature is typically associated with block pallets (Figure 2b). This design has blocks arranged to support a flat shipping surface, made from dimension lumber, plywood, or plastic, that is fastened to the blocks (Brindley, 2008). Accessibility and durability are some of the major advantages of block pallets. Also, they allow greater flexibility in the supply chain, and last longer before needing repair (Baker, 2015). Because of these attributes, block pallets are favored by pallet pooling companies, such as CHEP and PECO, who lease pallets to clients and coordinate the reverse logistics (Trebilcock, 2013). However, the construction of block pallets typically requires more material and is more expensive. A typical 48” x 40” GMA stringer pallet uses 15.8 board feet of wood, but 23 board feet of wood is used in the construction of CHEP’s 48” x 40” Mark 55 block pallet (Gomez, 2011).

The MH1 2016 standard lists “multiple use” and “single use” as the two main classes of durability for wooden pallets. Single use pallets are designed to handle only one unit load before disposal while multiple use pallets are intended to be loaded more than once (MH1, 2016). The durability of a pallet can be altered through the use of different amounts of materials and various grades of fasteners. The desired length of use is an important consideration in overall pallet cost and design.

One of the most critical features of pallet design is how many sides are accessible to material handling equipment. The GMA pallet has partial four-way access; it has full access on its 40” width side to both a forklifts and pallet handtrucks, but only partial access to a forklift on its 48” length side. The GMA stringer pallet has two notched locations in each of the three stringers. Stringers are the vertically oriented beams that run perpendicular to the deckboards and to which the deckboards are attached. While stringer notches add flexibility in how the pallet can interact with components of the distribution system, forklifts handling them from the length side lack the stabilization provided by the bottom deckboards. However, adding the notch reduces the depth of the beam resulting in a significant reduction in strength. Therefore, if there is no need for partial, four-way access within the distribution system, there is potential for cost savings in the pallet design. When the stringers on a pallet have no notches, forklifts and handtrucks can only access it from the 40” width side. It is said to have full, two-way access. For a summary of forklift entry modes, see Table 3.

Table 3 Summary of forklift and handtruck entry modes by pallet design

	Length Side	**Width Side**
Two Way	Not Possible	Forklift and handtruck
Partial Two Way	Forklift Only	Forklift and handtruck
Four Way	Forklift and handtruck	Forklift and handtruck

There are several other factors that can alter the performance of a pallet including stringer spacing and bottom deckboard arrangement. Wooden pallets’ bottom deckboard designs can be unidirectional, perimeter base, or cruciform. Stringer pallets and 800mm x 1,200mm Euro block pallets both have unidirectional bottom deckboards, meaning that all boards run in the same direction. Many block pallets use the cruciform bottom deck design for additional durability and strength (Figure 3).

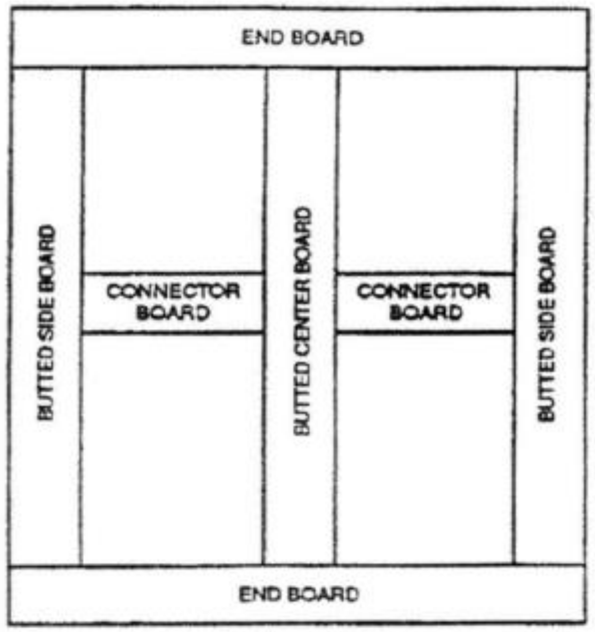

Figure 3 Illustration of perimeter and cruciform deckboard design with component names

Logistics systems around the world use a variety of pallet sizes to transport their goods. The most common pallet size used in the United States is the 48" x 40" (length x width). Many industries use a variety of pallet sizes especially in situations where large or specialty custom pallets are required (Bejune, 2001). A National Wooden Pallet and Container Association (NWPCA) survey found that 135 respondents produced 428 different pallet sizes (Bejune, 2001). In 2008, Bush and Araman examined the size breakdown of new pallet production by industry as shown in Table 4**Error! Reference source not found.** (Bush and Araman, 2008). Pallet sizes also vary greatly by region and country; the International Standards Organization has identified the most common pallet size by continent (Table 5).

Table 4 Sizes of new wood pallets produced in the United States (Bush and Araman 2008)

Use	Pallet Size (in.)	Share of Annual Production (%)
Grocery	48 x 40	26.9
Military	40 x 48	5.3
Chemical	42 x 42	4.8
Drums	48 x 48	4.3
Chemical, Beverage	48 x 42	3.7
Automotive	48 x 45	2.1
Beverage	37 x 37	1.6
Beverage, shingles, packaged paper	48 x 36	1.5
Other sizes	Various	50

Table 5 Pallet footprints recognized by International Organization of Standardization (ISO) 6780 (ISO 2001)

Dimensions (mm)	Dimensions (in.)	Region
1219 x 1016	48.00 x 48.00	North America
1200 x 1000	47.24 x 31.50	Europe, Asia
1140 x 1140	44.88 x 44.88	Australia
1067 x 1067	42.00 x 42.00	North America, Europe, Asia
1100 x 1100	43.30 x 43.30	Asia
1200 x 800	47.24 x 31.50	Europe

Because any given distribution systems generally achieve optimal costs when it is used at its greatest efficiency, the importance of pallet size should not be underestimated. A trailer or container can become full in two ways. The maximum weight capacity of the container can be reached allowing for no additional product to be carried in the trailer. This is known as being “weighed out”. Alternatively, the volume of the product can completely fill the space of the container. This is known as being “cubed out”. Ideally, any container will have 100% of its space utilized. Any void space reduces the percentage of space being utilized and results in inefficiencies. One cause of excessive void space could be the use of improper pallet sizes for the container. In a 2002 interview with Pallet Enterprise, Dr. Mark White commented on the challenges created by the lack of standardization by stating that "there are six international pallet sizes in the draft standard and that is five too many." The standardization of pallet sizes would save energy, conserve natural resources, and eliminate costs from the global supply chain (Buehlmann, Bumgardner and Fluharty, 2009).

1.4 Pallet Repair

Pallets inevitably break and become damaged during the rigors of transportation through the supply chain. Damage to pallets can occur through regular “wear and tear”, specific handling incidents such as being splintered with a forktine, or by exceeding the design specifications of the pallet through excessive weight or improper loading conditions. Because pallets are constructed from components, it is possible to repair and replace nearly any part of a pallet. The most common types of damage that lead to pallets being recycled are missing top deckboards and split stringer notches (Richard *et al.*, 1975). To fix these problems, pallet repairers replace broken deckboards, add companion stringers to support the original stringers, and/or add metal plates to maintain strength (Park, Horvath and

Bush, 2016). The methods of pallet recycling vary greatly depending on the firm, but they often include using bandsaws to cut through and disassemble pallets into stringers and deckboards then using nail-guns to attach new components together.

Park et al. found in a 2012 survey that the 69% of pallet repair facilities received cores (i.e. pallets needing to be repaired) collected within a radius of 11 to 50 miles of their facility location. Additionally, only 6% of facilities travel over 100 miles to collect pallet cores; and no respondent collected pallet cores from further than 200 miles (Park, Horvath and Bush, 2016). This suggests that travel distance is an important factor in the supply of recycled pallets. One simple explanation for this is that most pallets are commodities, meaning that the final selling price is tied closely to the purchase price of the raw materials, with little opportunity to add value or differentiate their product from their competitors. This makes higher transportation costs prohibitive as the additional cost would have to be passed onto the customer in order to maintain a profit, and this would then make the pallet seller’s prices uncompetitive.

Typically, the contamination level of shredded, used pallets is low, making the material safe for reuse as animal bedding or litter (White and McLeod 1989). Another common way to process pallet cores is to grind them into landscape mulch (colored and uncolored), fuel, and animal bedding (Bush and Araman, 2013). This allows facilities to process the unusable pallet pieces into a sellable product while avoiding the transportation and tipping fees associated with sending these materials to a landfill (Park, Horvath and Bush, 2016). In the 2012 study by Park et al, it was found that approximately 63% of pallet recycling firms ground wood on-site into mulch (Park, Horvath and Bush, 2016). Several factors contribute to a facility’s decision to have chipping equipment including finances, availability of space for grinding equipment, location of customers (industrial or residential), and regional market variation (LeBlanc 2003).

2.1 History of Landfills

Organic and inorganic wastes are an unavoidable byproduct of life on earth. The long-term storage of this waste needs important consideration due to the negative health consequences, such as disease and contamination that can be associated with it. In 1945, American anthropologist George P. Murdock presented a long list of characteristics that can be observed across all cultures known to history and anthropology. One of these universals is cleanliness, which is a concept that is tightly linked to waste management (Avlíček, Orcinek and Laub, 2016). Every prosperous civilization in history has had to consider how to deal with its waste otherwise it experiences "the most visible effects of lax attitudes towards waste, the common occurrence of diseases such as cholera, typhus, dysentery, hepatitis, and polio (Avlíček, Orcinek and Laub, 2016)." A 2012 World Bank report states that "While service levels, environmental impacts, and costs vary dramatically, solid waste management is arguably the most important municipal service and serves as a prerequisite for other municipal action (Hoornweg and Bhada, 2012)."

There are also significant issues surrounding air and water quality when there is poor management of waste. Until recent times, the most common approach to urban waste management involved dumping it just outside the boundaries of the home, town, or into the creeks and rivers. As Virginia Smith notes in her book "Clean", "Neolithic middens (a dunghill or refuse heap) were typically located directly outside the habitation, with further rubbish dumps on the outer boundaries of the settlement (Smith, 2008)." Even in ancient Rome, one of the most sophisticated cities of the ancient world, waste management was a constant challenge. The Roman poet and satirist Juvenalis wrote of the danger experienced just walking the streets when vessels of waste were tossed out windows (Avlíček, Orcinek and Laub, 2016). However, waste has not had the ability to diminish the quality of the entire ecosystem until the modern era (Letcher and Vallero, 2011). The increase in waste is largely due to increased economic activity and population growth.

Poor waste management is common in developing nations, and it was the norm throughout much of the history of the United States. For example, Louisiana officials justified the practice of dumping garbage into the Mississippi River. They rationalized that dumping trash into such an immense body of water that was in constant motion would result in only limited impact (Pichtel, 2005). However, the amount of waste the United States generated was minimal so the negative impacts were isolated. After the 1930's, when sanitary landfills became the universally accepted solution to municipal solid waste, waste management improved rapidly in efficiency (Aughenbaugh, 2012). Andreas Bartl, Vice Chair of the International Solid Waste Association's Working Group on Recycling and Waste Minimization, offers an insightful synopsis of how waste management developed over the 20th century:

> *"Over the past few decades, the attitude towards waste has dramatically changed. Up to the 1960's, waste treatment was basically a sanitary activity. Garbage was simply transported out of the cities to prevent epidemic diseases. Since the 1970's, waste management has progressed in most parts of the world and especially in the developed countries such as the European Union, the United States, and Japan. Initially technologies were developed to prevent environmental problems at landfill sites. Later on, recycling strategies for special types of waste such as glass or paper were introduced. Parallel to this, waste incinerations with highly efficient gas cleaning devices have been extensively installed. Today, waste is increasingly seen as (secondary) raw material, and 'zero waste' represents the current ideal in waste management* (Letcher and Vallero, 2011)*."*

The modern waste management industry is comprised of a sophisticated network of waste haulers, transfer stations, landfills, composters, incinerators, and recyclers. Its core mission is to safely isolate any toxic waste while promoting all recovery efforts. Waste is increasingly viewed as an inefficiency that should be completely eliminated. Innovations in design methodology and recycling technology help foster this 'zero waste' mission, which seeks to eliminate pre and post-consumer waste through both product design and recycling. Research regarding these markets announced that the global solid waste management market will reach $1.3 trillion dollars by 2022 (*Global $1296.04 Billion Solid Waste Management Analysis and Forecasts 2017-2022*, 2017).

Solid waste management employs a disposal hierarchy to guide decision making for waste producers and landfills. Reduce, reuse, and recycle are the basic tenets followed in order to reduce the waste generated and divert it from the landfill. Reduction is the best and most efficient method for minimizing waste and associated disposal issues (Peng, Scorpio and Kibert, 1997). The reuse and recycling of materials are also desirable ways to manage waste, and these provide many benefits over landfilling. If waste cannot be reduced, reused, or recycled, then the most desirable methods to dispose of it are composting, followed by incineration, and then landfilling. Ideally, these principles are utilized to minimize waste in the design, production, and disposal of goods. This visionary concept is commonly known as "zero waste."

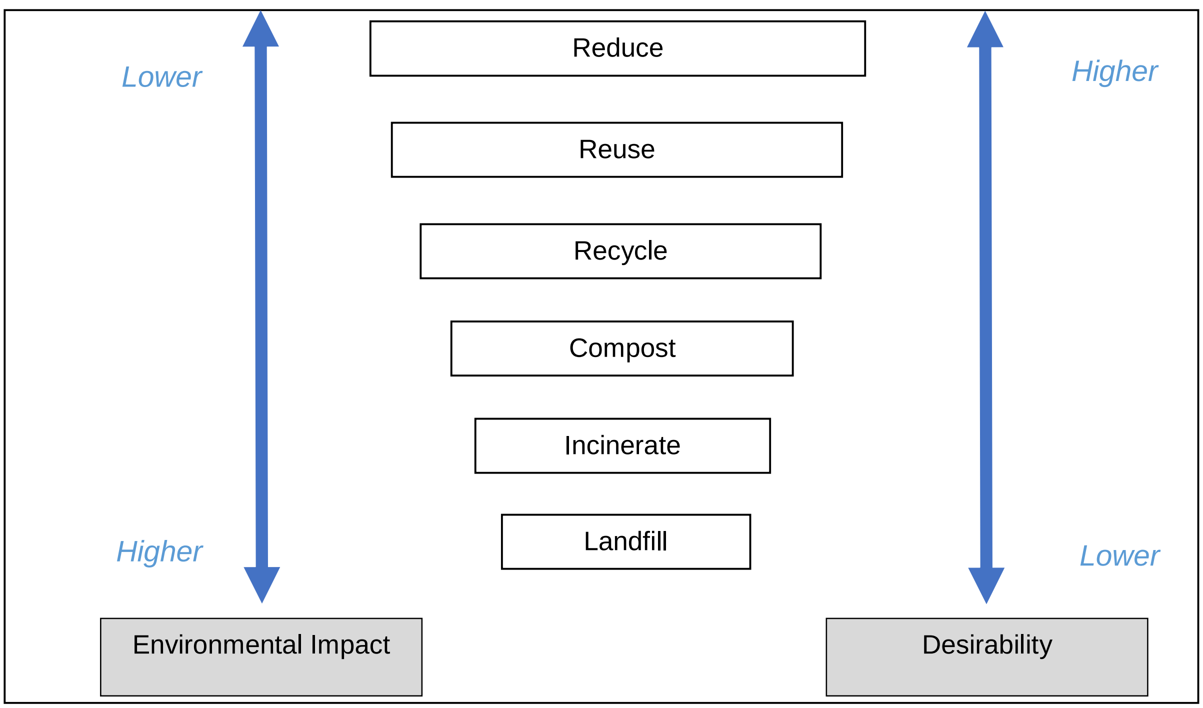

Figure 4 Principles of the waste hierarchy. Adapted from figure 1 of Pent et al 1995 (Peng, Scorpio and Kibert, 1997)

In her analysis of *Overcoming Challenges to Zero Waste in Massachusetts*, Laura Crossley observes that, “Definitions of zero waste vary, with some defining it primarily as a philosophy and others as a goal to be achieved.” Rather than drawing hard lines with strict definitions, advocacy and governmental groups describe zero waste as a visionary process (Crossley, 2013). Thus, the strategy of zero waste may not necessarily lead to specific results, such as 100% of waste being diverted from landfills, but instead this strategy serves as a vision to help guide policy making and promote a shift away from the traditional models of waste-management and manufacturing. As Eric Lombardi has noted, “One-hundred percent is not the point. If anybody hangs on to that, they’re missing the point (Crossley, 2013).” At the core, the concept of zero waste is a holistic plan designed to consider the most effective, long-term ways to manage resources.

The Zero Waste International Alliance provides a concise summary of some of the overall goals: “Zero Waste is a goal that is ethical, economical, efficient, and visionary, to guide people in changing their lifestyles and practices to emulate sustainable natural cycles, where all discarded materials are designed to become resources for other to use. Zero Waste means designing and managing products and processes to systematically avoid and eliminate the volume and toxicity of waste and materials, conserve and recover all resources, and not burn or bury them (“ZW Definition”, 2009).”

2.2 Regulation of Waste

Most landfills are regulated through state and federal legislation which offer guidelines on acceptable waste criteria, operating procedures, emission limits, data reporting, and construction standards. Throughout the 1960's, the federal government faced mounting pressure to address the environmental concerns of landfills and thus several pieces of legislation were enacted. The Solid Waste Disposal Act of 1965 and Resource Recovery Act of 1976 were the first federal attempts to help regulate municipal waste disposal technology, develop standards for waste disposal, and increase federal involvement in the management of waste (US EPA, 2017a). The most prominent federal regulations pertaining to landfills are Subtitles C & D of the Resource Conservation Act of 1976, which regulate the management of hazardous and nonhazardous solid waste, respectively. “These establish the minimum federal technical standards and guidelines for state solid waste plans in order to promote environmentally sound management of waste (US EPA, 2017a).” They also regulate the generation, transportation, treatment, storage, and disposal of hazardous waste. It is a federal statute that was intended to ensure the “cradle to grave” management of hazardous waste and also sets standards for the management of non-hazardous waste solid wastes. Amendments were made to the RCRA in 1984 and 1992.

The Hazardous and Solid Waste Amendments of 1984 expanded and strengthened the RCRA. It made over 70 provisions including creating land disposal restrictions, facility-wide corrective actions, specific permitting deadlines for hazardous waste facilities, a nationwide assessment of solid waste landfill conditions, and the regulation of underground storage tanks (EPA Archive). In 1992, the Federal Facility Compliance act was passed. This was the first time that federal regulations set minimum standards for the design, closure, and post-closure care of MSW landfills. Any existing Subtitle D classified landfill that could not meet the new facility minimums could not continue operating after September 9, 1996 (Tomarelli, 2008). Due to the costly technological improvements that would have been required to meet these new standards, many solid waste facilities chose to exit the market during this period.

Because of the Federal Facility Compliance Act, the number of landfills decreased dramatically through this period. The number of MSW facilities decreased from 2,829 in 1995 to 1,669 in 1998 (Corr *et al.*, 2000). A variety of other federal regulations apply to landfills as well including the Clean Water Act (CWA), Safe Drinking Water Act (SDWA), and the Clean Air Act, which regulate a variety of gaseous emission levels permissible at landfills. The legislation applicable to landfills is extensive, but it is critical to maintain high standards of protection for the health of people, the environment, and the surrounding area.

2.3 Landfills and the Environment

There are several different types of landfills categorized based on the type of waste they are designed to store. Within the United States, state environmental protection agencies classify them according to the types of waste they are allowed to receive as well as by the volume of waste that they are permitted or expected to receive. Many states have a unique classification system specifically for permitted facilities which are publicly accessible. State regulations often build upon the Federal framework to provide construction requirements and operating policies. Landfill construction is important because they can damage the surrounding environment with air and ground water pollution.

Open dumps are the most basic types of landfills. They are unlined and typically located in low, swampy areas, ravines, old gravel pits, or other mined-out pits (Aughenbaugh, 2012). These simple landfills used to be common in the United States, and they are still seen in many parts of the developing world. Because there are no requirements for daily use of soil to cover the waste, hazards such as vectors (objects that spread infections by carrying pathogens) are created (*Reference Terms*, 2017). One of the greatest concerns about landfills that are built without protective, subsurface liners is that they cannot prevent leachate from permeating the subsurface contents that are leaking into geologic formations, including groundwater aquifers (Pichtel, 2005). Leachate is the liquid generated through the interaction of rain water and waste. Leachate composition varies depending on the type of waste that the landfill contains, rainfall conditions, landfill design and operation, and landfill age (Stucki, Wochele and Brandl, 2003). Most landfill leachate consists of some or all of these four groups of pollutants:

1. Dissolved organic matter, expressed as Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC), also including methane and volatile fatty acids;
2. Inorganic macro-compounds such as calcium, magnesium, sodium, potassium, ammonium, iron, manganese chloride, sulfate, and carbonate;
3. Heavy metals such as cadmium, copper, chromium, lead, nickel, and zinc;
4. Xenobiotic organic compounds such as aromatic hydrocarbon (Stucki, Wochele and Brandl, 2003).

When the pollution of rivers and groundwater was directly traced to the uncontrolled dumping of toxic waste into dumps and pits, it prompted the creation of federal regulations and established a permitting process requiring that landfills meet certain standards in order to protect the surrounding air, water, and wildlife. It also made geology a critical factor in landfill site selection by requiring that "the local geology must contain thick and continuous clay soils or their rock equivalent, shale (Aughenbaugh, 2012)." This type of soil and sediment has low permeability and hinders the spread of leachate in case of liner failure. Other considerations such as wetlands, floodplains, and airports can affect site selection. Critical safeguards against groundwater contamination are specified by the RCRA and include installing an impermeable liner and leachate collection systems, in addition to requiring favorable soil composition.

Uncovered waste can pose a variety of risks including vectors, fires, odors, and scavenging by animals. The high presence of birds at landfills explains the problem with selecting a site near an airport (Pichtel, 2005). To remedy this, 40 CFR 258.21 of the RCRA requires that active landfills be covered daily with at least 6 inches of soil or similar materials also known as Alternative Daily Cover (ADC) (Pichtel, 2005). "According to fire incident reporting data for municipal landfills in the US from the Federal Emergency Management Agency, approximately 839 unique landfill fire incidents were estimated to have occurred in the US annually from 2004-2010, and more than 25% of these incidents were repeated at the same site" (Powell, Townsend and Zimmerman, 2015). If dirt is unavailable, landfill managers have several options for ADC. They can use waste-derived materials like ash, auto shredder fluff, construction and demolition (C&D) waste, compost, and green waste such as vegetation, leaves, and wood. Landfill managers can also utilize non-waste derived materials such as spray-on foams, slurries, and reusable geosynthetic covers (Fantell and Flannagan, 2011). "ADCs can serve as another source of revenue for a landfill, because in addition to tipping fees and renewable energy from landfill gas, and getting paid to take a material instead of having to spend money on hauling on-site soil or procuring soil from off-site, landfill managers can greatly reduce operating costs and improve their bottom line (Fantell and Flannagan, 2011)."

Landfills also are a major source of Green House Gases (GHG). MSW is responsible for 5% of total global greenhouse emissions (Hoornweg and Bhada, 2012). This occurs from anaerobic decomposition of organics within the landfill. This gas is typically composed of approximately 50% methane and the rest is carbon dioxide and other gases. Methane has 21 times more of a global warming effect than carbon dioxide and is the second most common greenhouse gas (Hoornweg and Bhada, 2012). However, methane can be collected and used as a source of energy. The Facility Compliance Act requires MSW landfills to capture methane along with reducing by 98% the non-methane organic compounds (NMOCs) in collected landfill gas. "Collected LFG can be either combusted with or without energy recovery (for steam or electricity generation) or refined to pipeline quality natural gas (Themelis, 2014)."

2.4 Types of Waste

Only a few studies have attempted to make high level estimates of the global or even national total waste. It has been estimated that the United States generates more than 11 billion tons of solid waste each year (Aughenbaugh, 2012). This statistic includes all types of waste, however most studies focus on a particular type of waste. The most familiar type of waste is known as municipal solid waste (MSW), and it is comprised of product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, batteries, etc… that have been discarded from homes, school, hospitals, and businesses (US EPA, 2017c). It makes up a relatively small portion (by weight) of all the waste that is generated, yet Municipal Solid Waste collection is the most important service a government can provide in low-income and middle-income counties. Poorly managed waste has a very significant impact on public health, the local environment, and the economy (Hoornweg and Bhada, 2012).

Construction and Demolition Waste (C&D) are materials generated during the construction, renovation, and demolition of buildings, roads, and bridges (EPA, 2017b). The United States Environmental Protection Agency (US EPA) estimates that 534 million tons of C&D debris were generated in 2014, which is more than twice the amount of MSW. A large portion of the total waste stream is industrial waste, which is a broad category comprised of waste water, sludge, flying ash (a product of coal combustion), and byproducts from the pulp, paper, steel, and chemical industries. Additional types of waste include hazardous, medical, universal, mining, and agricultural. Each of these types of waste are regulated separately through specific federal and state regulations.

Municipal Solid Waste: This includes waste generated by homes, hospitals, schools, and businesses. Facilities operating under this classification can be privately or publicly owned. The Environmental Research and Education Foundation reported in 2013 that approximately 65% of MSW landfills were publicly owned, but the majority of waste tonnage generated is managed by private landfills (Environmental Research and Education Foundation, 2013). As previously discussed, these facilities are regulated to include environmental safeguards and have proper zoning.

The US EPA estimates that 258 million tons of waste were generated in 2014 (United States Environmental Protection Agency, 2016). The EPA splits this waste into the categories of durable goods, nondurable goods, and packaging and containers. This is achieved using a materials balance method that incorporates data from sources such as industrial associations, major companies, and government agencies (i.e., Department of Commerce) (Themelis, 2014). Any waste that is diverted from landfills through recycling, combustion, or composting is subtracted from the total weight of waste generated in order to reach an estimate of the total weight of waste landfilled. In some situations, data is adjusted using statistics provided by academics, research, or consulting groups. Overall, this number (Figure 5) has increased steadily each year, since 1960, as it is correlated to GDP (Figure 6) and population growth.

Because the EPA has been conducting waste and landfill research since 1960, it is generally regarded as the standard for MSW estimation. However, other researchers have significantly different estimates for the total weight of waste generated. The Earth Engineering Center (EEC) of Columbia estimated nearly one hundred million tons more than the EPA in 2012 (Themelis, 2014). To gather data for this study, a survey was sent to the Solid Waste management agencies of each of the fifty states that comprise the United States of America. The states were asked to provide similar metrics to the materials balance method from the EPA including rates of composting, combustion, and recycling as well as the total weight of waste landfilled. Because of the wide range of responses, the lack of data tracking capabilities, and the inability to acquire data from certain states, several adjustments had to be made to make the analysis comprehensive. The large difference between estimates may be partially accounted for by the unrepresented waste in the EPA's method such as C&D waste that ends up in MSW landfills. The EPA estimates also cannot account for moisture content, residual contents in partially filled food and product containers, packaging from international shipping, animal carcasses, and counterfeit good wastes (Themelis, 2014).

Several groups have provided estimates for MSW generation in the United States. These include the Environmental Research and Education Foundation (EREF) who reported 347 million tons of MSW in 2013, and The World Bank who estimated that the urban population of 241,972,393 people produce 687,648 tons per day or 250,991,520 tons of MSW (Hoornweg and Bhada, 2012). The EREF used a facility based approach similar to the methodology for this study; however, their research questions focused on total MSW generation and did not investigate wood and wood packaging.

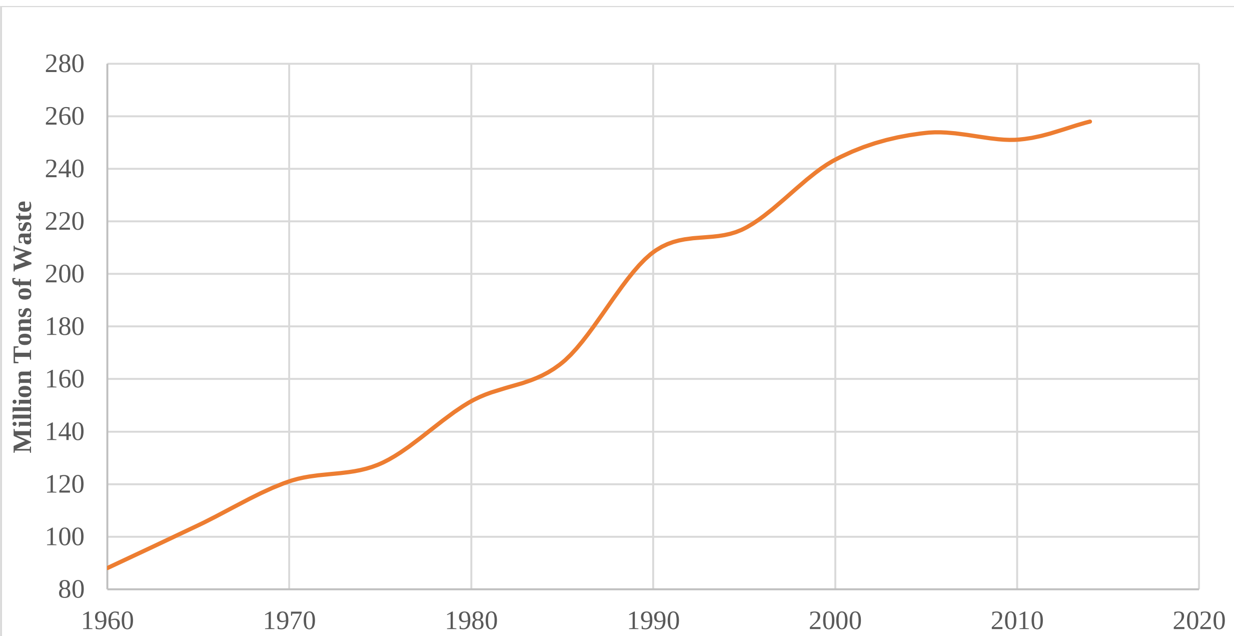

Figure 5 EPA estimate of total Municipal Solid Waste generated in the US from 1960 to 2014 (United States Environmental Protection Agency, 2016)

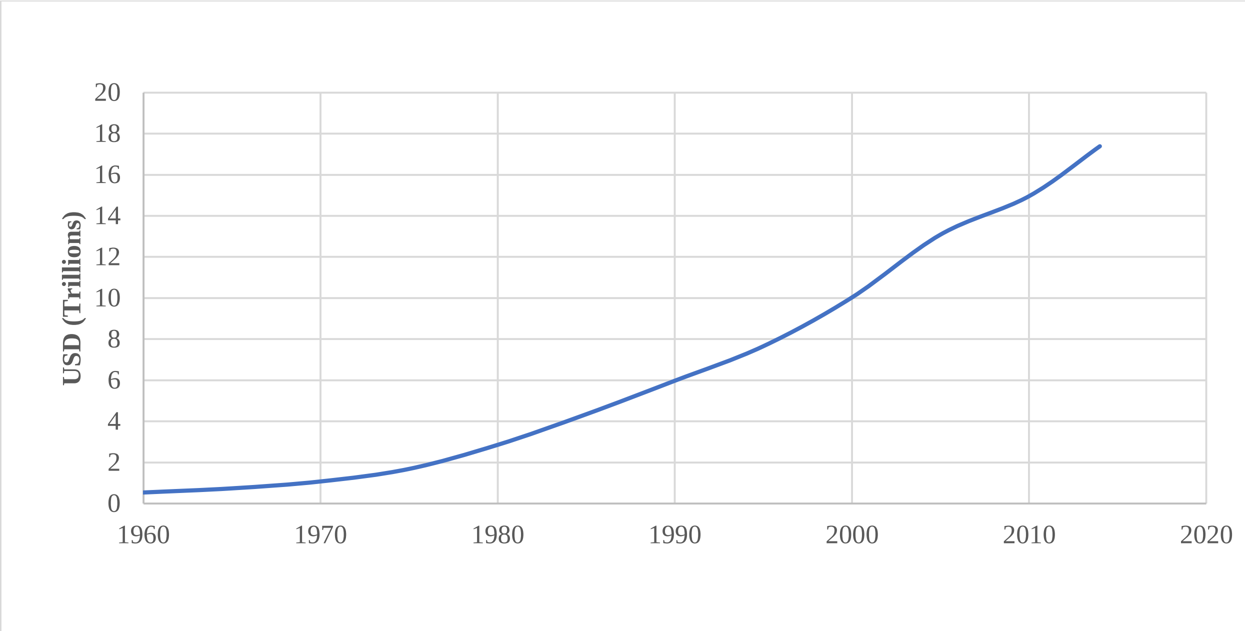

Figure 6 US Gross Domestic Product (GDP) from 1960 to 2014 (US Department of Commerce, 2016)

Some materials are banned from being landfilled in certain states. Nearly every state prohibits tires and lead-acid batteries from being landfilled, and at least 25 states ban the landfilling of yard trimmings. A list of banned materials by state is shown in Table 6 (Van Haaren, Themelis and Goldstein, 2010). There are a variety of reasons for banning certain materials from the landfill. For example, tires have a high potential to catch on fire and produce harmful smoke. Tires have also led to safety related incidents at landfills; they sometimes "rebound" after being compressed (*Environmental Impact of Scrap Tires*, 2017).

Table 6 Materials banned from in US MSW landfills by State (*van Haaren, Themelis, & Goldstein, 2010)*

State	Yard Trimmings	Containers, Paper	Whole tires	Used Oil	Lead-Acid Batteries	White Goods	Electronics	C&D	Other
Alabama				X	X				
Alaska				X	X				
Arizona			X	X	X				
Arkansas	X		X		X				
California			X	X	X	X	X		
Colorado			X	X	X		X		
Connecticut	X		X		X				
Delaware	X		X						
Florida	X		X	X	X				
Georgia	X		X	X	X				
Hawaii			X						
Idaho			X		X				
Illinois	X		X	X	X	X			X
Indiana	X		X						
Iowa	X		X	X	X	X			X
Kansas			X						
Kentucky			X		X				
Louisiana			X	X	X	X			
Maine			X	X	X	X	X		X
Maryland	X		X	X	X				
Massachusetts	X	X	X		X	X	X	X	
Michigan	X	X	X	X	X				
Minnesota	X		X	X	X	X	X	X	
Mississippi			X		X				
Missouri	X		X	X	X	X			
Nebraska	X		X	X	X	X			
New Hampshire	X		X	X	X		X		
New Jersey	X	X	X	X	X	X	X		
New Mexico					X				X
New York			X	X					
North Carolina	X	X	X	X	X	X			X
North Dakota					X	X			
Ohio	X								
Oregon			X				X		
Pennsylvania	X		X		X				
Rhode Island	X	X	X	X	X	X	X		
South Carolina	X		X	X	X	X		X	
South Dakota	X		X	X	X	X			
Tennessee			X	X	X				
Texas			X	X	X		X		
Utah			X	X	X				
Vermont	X	X	X	X	X		X		
Virginia			X		X			X	
West Virginia	X		X	X	X				
Wisconsin	X	X	X	X	X		X		
Wyoming				X	X				

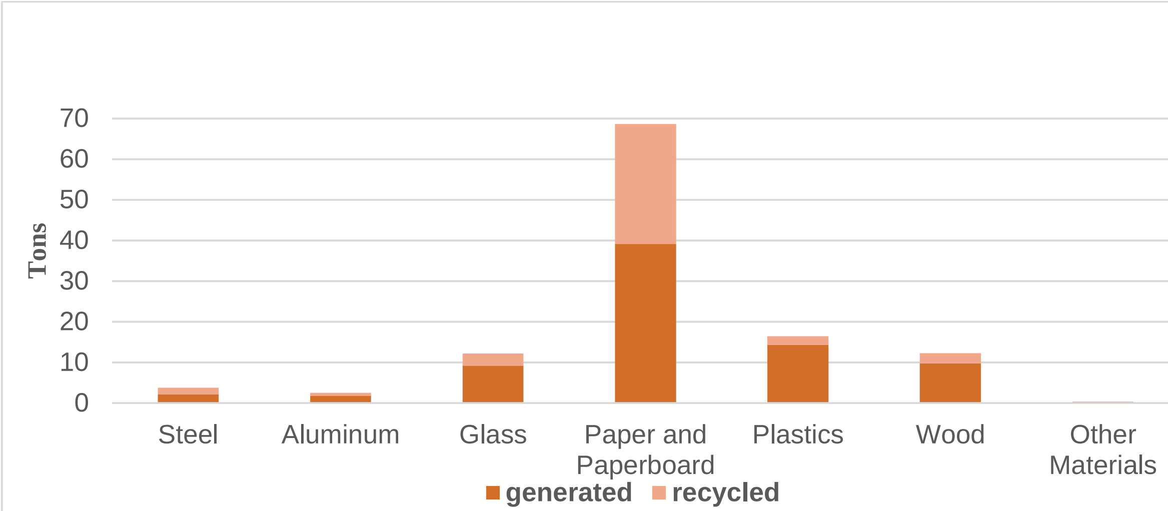

Figure 7 EPA estimate of weight generated compared to waste recycled for Containers and Packaging within MSW in 2014

States often ban recyclable organics to help preserve landfill space and provide material for composting. For example, in 2005, North Carolina implemented House Bill 1465, which "prohibits the disposal of motor oil filters, rigid plastic containers, wooden pallets, and oyster shells" from being landfilled at MSW facilities (*Session Law 2005-362. House Bill 1465.*, 2006). Instead businesses are expected to work with pallet recycling and pallet repair facilities to reuse or repurpose pallets instead of sending them to the landfill. However, pallets used during building related activities can be disposed of at C&D facilities. In a survey to North Carolina pallet recyclers in 2009, Buehlmann et al found that 56% of recyclers thought that the ban was a good idea; however, industry participants were concerned about the lack of a market for recycled pallets, and a flood of supply could cause prices to drop (Buehlmann, Bumgardner and Fluharty, 2009).

Construction and Demolition Waste: Construction and Demolition (C&D) debris includes any waste created in the building or destruction of residential homes, commercial structures, and public works projects such as streets, highways, bridges, and piers (Pichtel, 2005). It is estimated that there are more than 1,500 C&D landfills operating in the United States (Powell *et al.*, 2015). There is less information characterizing the C&D waste stream than the MSW, but several attempts have been made. According to the EPA, the amount of C&D waste generated was more than double the amount of MSW generated at 534 million tons. Since the C&D waste stream often has high-value materials in it, recycling and sorting are common. Because of the problems associated with C&D waste, it is usually "more cost-effective to process C&D waste for recycling and composting than for incineration and landfilling when full cost accounting is considered (Peng, Scorpio and Kibert, 1997)." Over 90% of the total C&D waste generated is from demolition related activities, and the remaining waste generated is from building related activities (United States Environmental Protection Agency, 2016). Although the EPA doesn't offer estimates on C&D waste recovery, only a portion of the total C&D waste generated is landfilled.

C&D material is generally considered inert, and because of this, "U.S. rules do not require CDD disposal facilities to be constructed with liners and leachate collection and removal systems (LCRS), but approximately half of U.S. states require such containment systems and about half of U.S states require routine groundwater monitoring (Powell *et al.*, 2015). Results of the research conducted by Jon Powell of Yale indicate that while the surrounding area is at minimal risk for contamination, water in the vicinity of the site may be nonpotable (Powell, Townsend and Zimmerman, 2015). However, in a 2006 interview with Biocycle, Bob Brickner of Gershman, Brickner & Bratton, Inc. (GBB), stated that he believes that as more state regulators become aware of the importance of a liner, old C&D landfills will close and new ones will be built following stricter regulations (Goldstein, 2006).

Industrial Waste: This is waste generated as the byproduct of the manufacturing industries. Industrial wastes may arise from mining, petroleum extraction and refining, agriculture, energy production, construction, demolition, transportation, and manufacturing activities. The unintended by-products of industrial production may contain hazardous substances and typically are generated in high volumes. It is estimated that amount of nonhazardous industrial waste was 7.6 billion tons in 1987, which is still the statistic reported by the EPA (Zimring and Rathje, 2012). This waste is often disposed of in facilities separate from municipal waste landfills because of the need to guarantee disposal capacity and lower costs. Many ash producers, especially electric utilities, construct their own landfills designed solely to accept ash because they need to dispose of so many tons. Landfill sites specifically designed to hold this ash are often referred to as monofills (O'Leary, Waste Age 2002).

Hazardous Waste: As described in 40 CFR 240.101 of the Resource Conversation and Recovery Act, "Any waste or combination of wastes, which pose a substantial present or potential hazard to human health or living organisms because such wastes are non-degradable or persistent in nature or because they can be biologically magnified, or because they can be lethal, or because they may other cause or tend to cause detrimental cumulative effects."

Typically, hazardous waste requires documentation of its handling, storage, and treatment. The facilities that handle it must be built to the specifications outlined within the RCRA (Pichtel, 2005).

Medical Waste: Waste generated during the administration of healthcare by medical facilities and home health care programs. Not all of this waste poses a biohazard, but regardless, most facilities handle all of their waste as potentially infectious (Pichtel, 2005).

Universal Waste: As described in 40 CFR 273 of the RCRA, universal waste includes batteries, pesticides, and mercury-containing equipment and lamps. These materials must be handled in a way that prevents the release of harmful substances into the surrounding environment (US EPA, 2017b). This is one of the few types of waste permitted to use alternative regulatory controls when it is recycled along with used motor oil, materials utilized for precious metal recovery, and hazardous waste burned in boilers and industrial furnaces (EPA, 2017a).

Mining Waste: "Mining waste includes materials that must be removed to gain access to the mineral resource, such as topsoil, overburden, and waste rock, as well as tailings remaining after minerals have been largely extracted from the ore (*Extractive Waste*, 2017)." Estimates of the total amount of mining waste generated by weight are limited, but they typically range between 1 and 2 billion tons annually (Pichtel, 2005).

Agricultural Waste: "Agricultural waste is waste produced as a result of various agricultural operations. It includes manure and other wastes from farms, poultry houses and slaughterhouses; harvest waste; fertilizer run-off from fields; pesticides that enter into water, air, or soils; and salt and silt drained from fields (Development, 2017)." In the United States, agricultural waste is produced in much greater quantities than MSW (Pichtel, 2005).

2.5 Tipping Fees

A tipping fee is the amount that waste haulers need to pay the landfill to dump a certain amount or volume of waste. This term comes from the fact that trash collection vehicles usually dump their contents by tipping the container on the back of the truck. Tipping fees can vary significantly depending on the type of waste the hauler is bringing and the region in which the landfill is located. In 2014, the EPA estimated that the average tipping fee at US MSW landfills was $50.59 (United States Environmental Protection Agency, 2015). Virginia Tech studies found that the average tipping fee for MSW was $32.22 in 1995 and $29.31 in 1998, which are $52.91 and $44.77, respectively, when adjusted for inflation using Consumer Price Index (CPI) for the appropriate time periods. The same study also found that the average tipping fee for sorted wood waste was $22.40 in 1995 and $23.55 in 1998, which are $36.78 and $35.97 when adjusted to present value using CPI.

Landfills can charge different tipping fees depending on the category of waste. For example, a ton of sorted wood that can be diverted to a recovery area often costs less than a ton of waste that will have to be landfilled. This incentivizes waste haulers to sort and recycle their waste whenever possible, leading to a longer operational life of the landfill. Since many landfills are essentially municipal services, not for-profit entities, the additional value they derive from the sale and repurposing of wood materials means that they can lower the price of the tipping fees because some of that revenue will be recovered elsewhere. Even if facilities cannot sell mulch or fuel to outsiders, chipped wood can be used as a material for alternative daily cover (ADC), or for road construction, within the facility. When materials like these are brought to the landfill, it saves costs associated with purchasing and transporting daily cover material.

Some facilities use volume instead of weight to calculate tipping fees. This is especially common in construction and demolition facilities. Part of the reason for this is that receiving waste that is already compacted saves the facilities time and labor. However, many landfills also have special rates for certain materials such as wood. In the 2000 study from Corr et al at Virginia Tech, it was found that the average tipping fees for standard waste received at C&D facilities decreased from $24.18 in 1995 to $16.85 in 1998, which are $39.71 and $25.74, respectively, when CPI is used to adjust them to present value. The same study found that tipping fees for sorted wood waste brought to C&D recovery areas also decreased from $21.94 in 1995 to $18.57 in 1998, which are $36.03 and $28.36 when using CPI to adjust for inflation from January the year of the study to September of 2017.

2.6 Yard Trimmings

One of the largest sources of organic waste is called woody yard waste or yard trimmings. “This includes all woody and herbaceous vegetative material such as grass, leaves, and tree and brush trimmings from residential, institutional, and commercial sources (Falk and McKeever, 2004).” The EPA estimated that yard trimmings made up

13.3% of all MSW generated, behind only food and paper as the largest categories of waste (United States Environmental Protection Agency, 2015). Yard trimmings also represent 23.6% of all materials recycled or composted by volume, with only paper and paperboard making up a larger portion at 49.7% (United States Environmental Protection Agency, 2016). The 1995 and 1998 surveys conducted by Virginia Tech did not attempt to estimate woody yard waste generated. The EPA does not track yard trimmings for C&D facilities, however it does track the generation of wood products waste.

2.7 Wood Waste

The average production of wood products in the United States over the past thirty years has been 143.3 million tons annually (Howard 2012) (Falk, Mckeever 2012). The manufacture, use, and disposal of these wood products generates a large amount of waste. According to a report by Dovetail Associates, "wood product companies in the U.S. and Canada utilize nearly 99% of their manufacturing inputs (pre-consumer recycling) at sawmills and at secondary wood processors such as furniture and cabinetmakers." However, much greater quantities of post-consumer waste are generated. In 2010, Falk and McKeever of the USDA Forest Service estimated that 70.6 million tons of solid wood waste was generated through the manufacture, use, and disposal of solid wood products (Falk and McKeever, 2012).

The EPA estimated that over 16 million tons of wood waste was generated in the MSW stream in 2014. Approximately 2.57 million tons of this was recycled or composted (United States Environmental Protection Agency, 2015). An additional 2.54 million tons of waste was combusted for energy recovery. The wood waste estimate from the EPA includes items such as wooden furniture and cabinets, pallets and containers, scrap lumber and wooden panels, and wood from manufacturing facilities (Howe, Jeff, Steve Bratkovich, Jim Bowyer, Matt Frank, 2013). Wood waste has a high potential for reuse, recovery, and recycling, because it has such a large variety of uses including mulch, soil amendment, fuel, or reuse.

The C&D waste stream is comprised of 7% wood products, or approximately 38.7 million tons (United States Environmental Protection Agency, 2015). Of this, it is estimated that 2.9 million tons were generated during construction related activities and 35.8 million tons were created during demolition. Processed (chipped) wood can be used as mulch, composting bulking agent, animal bedding, and fuel. However, mixed wood waste can be problematic for C&D processors due to painted and treated pieces of wood going through the sorting line (Goldstein, 2006). Because construction materials are often transported on pallets to construction sites, significant numbers of pallets end up at C&D landfills. Wood waste from C&D is attractive as fuel because of its low moisture content. “Depending on the wood waste boiler system design and the state/regional air pollution permit requirements for the facility, a level of quality control may be necessary at the wood processing plant to reduce and/or avoid the processing of treated and/or painted wood if used as a fuel source in a combustion process (Turley *et al.*, 2000).”

Chromated copper arsenate (CCA) has been the most commonly used wood preservative in North America for the past several decades, accounting for 79% of all treated wood production (Townsend *et al.*, 2004). "Discarded CCA-treated wood is exempt from characterization as a hazardous waste in the U.S., even though it often leaches arsenic at concentrations greater than the U.S. Environmental Protection Agency (EPA) characteristic concentration for hazardous waste (Jambeck, Townsend and Solo-Gabriele, 2006).” Because of this exemption, it can be processed at both MSW and C&D facilities, however most discarded CCA- treated wood is managed as part of the construction and demolition waste stream. While operators attempt to identify treated wood, it often becomes an area of concern as CCA preservatives can make their way into recovered mulch where it is then difficult to remove (Jambeck, Townsend and Solo-Gabriele, 2006). To confront this challenge, waste management professionals conduct required leaching tests for the presence of hazardous chemicals (Townsend *et al.*, 2004).

2.8 Wood packaging waste

In 2014, just over 25% of the 9.68 million tons of MSW that was wood packaging was recycled or composted. In 2014, the EPA found that 29.7% of all MSW generated, more than 76 million tons, was comprised of containers and packaging. Containers and packaging are assumed to be discarded at the same time as the products that they contain are purchased. These include bottles, containers, corrugated boxes, milk cartons, folding cartons, bags, sacks, wraps, wood packaging, and other miscellaneous packaging (United States Environmental Protection Agency, 2015). Within the category of containers and packaging, paper and paperboard has the highest rate of recycling at 75.4% of total paper and paperboard waste generated, while wood containers and packaging had a recycling rate of 26.4%, mostly due to the recovery of wood pallets (United States Environmental Protection Agency, 2015).

In 1995, the Center for Forest Products Marketing and Management at Virginia Tech conducted a survey in cooperation with the USDA Forest Service to investigate the disposal and recovery of wood and packaging materials made from wood in the United States. It surveyed MSW and C&D landfills utilizing a “bottom up” facility survey approach. The overall aim of the study was “to provide valuable information on alternatives to wood pallet landfilling while developing economic recovery options that reduce environmental issues and raw material extraction (Araman *et al.*, 1998)." It investigated several questions pertaining to the weight of pallets being sent to landfills in the US, the number of landfills that had pallet recovery operations, and average tipping fees.

The 1998 survey performed by Daryl Corr at Virginia Tech contained very similar questions to the 1995 survey, allowing researchers to analyze trends from the previous study. Overall, it was found that the total number of pallets received at MSW landfills decreased from 152,745,000 in 1995 to 138,360,000 in 1998. However, the number of pallets recovered also decreased from 32,030,000 in 1995 to 22,052,000 in 1998. Additionally, the number of facilities that had the ability to recover wood decreased from 37.9% in 1995 to 33.4% in 1998. It notes that the decreasing number of landfills combined with the increasing amount of waste has both a positive and negative effect on the recovery of waste. Larger facilities are more likely to have recovery equipment, but they can charge lower tipping fees creating a disincentive for waste producers to sort their waste (Corr *et al.*, 2000). Possible explanations for the decrease in pallets reaching landfills from 1995 to 1998 include more pallets being reused before entering the waste stream, increased delivery of parcel packages from direct ship retailer, plastic pallets taking market share, and fewer pallets taken out service in 1998 than in 1995 (Corr *et al.*, 2000).

3. An Investigation of Wood Pallets Landfilled and Recovered at US Municipal Solid Waste (MSW) Facilities

Zachary Shiner, Laszlo Horvath, Philip Araman

The purpose of this research was to investigate the total number of pallets that end up in landfills in the United States as well as to gain a better understanding of the overall waste stream. This research was conducted by mailing all of the licensed Municipal Solid Waste (MSW) facilities in the continental United States a questionnaire that included the option to complete the survey online. The questionnaire that was sent to the landfills was built upon previous surveys conducted by researchers at Virginia Tech in both 1995 and 1998. The results indicate that an estimated 24 million tons of MSW was received at landfills nationwide. This is an increase from the 239 million tons of MSW in 1998. Regionally, the South received 75% of all wood landfilled and 69% of all wood recovered. Only 13.1 million pallets were landfilled in 2016, which is over a 90% decrease from the 138 million pallets landfilled in 1998. At the same time, approximately15.9 million pallets were recovered, repurposed, or reused at the surveyed MSW facilities, which is a decrease from the 22 million pallets recovered in 1998. The results of this research indicate that fewer pallets are making their way to landfills, and a greater proportion of pallets reaching MSW facilities are being recovered.

Keyword: Municipal Solid Waste (MSW), Wood Pallets, Wood Waste

Author Contact: Department of Sustainable Biomaterials, Virginia Tech, 1650 Research Center Dr., Blacksburg, VA 24061, USA; *Corresponding author: lhorvat@vt.edu

3.1 Introduction

Municipal Solid Waste (MSW) is waste that has been generated by private residents, commercial businesses, restaurants, and public institutions like schools and hospitals. It does not include industrial, hazardous, or construction waste (United States Environmental Protection Agency, 2016). The United States generates significant amounts of MSW. Several organizations are already studying the waste stream to gain a better understanding of the landfilling and recovery rates of certain materials. This information can also be used to understand the effectiveness of recycling programs, the impact of waste regulations, and to predict waste generation rates in the future. The Environmental Protection Agency (EPA) utilizes material flow methodologies based on data provided by the U.S. Department of Commerce and trade organizations to quantify the materials and products that are being generated. This number is then adjusted to take into account a variety of factors such as product lifetime, diversion, recovery rates, and imports/exports. The most recent EPA study estimated that 258.5 million tons of MSW was generated in 2014 (United States Environmental Protection Agency, 2016). Other studies have relied on different methodologies, communicating directly with MSW facilities or state government waste agencies. Those studies resulted in estimates that were very different than the EPAs. For example, the Earth Engineering Center (EEC) at Columbia University collected information from state waste management agencies that estimated 389 million tons of MSW was generated in 2013, which is over 100 million tons higher than the EPA's estimate for the same year (Themelis, 2014). However, not all of the waste in the EEC's study was landfilled; much of it was recycled, composted, or incinerated before then being buried in the landfill. The EEC report found that 29% of the MSW generated was either recycled or composted, 7.6 % was sent to WTE facilities, and only 63.5% was actually landfilled (Themelis, 2014).

A significant portion of the MSW generated each year is comprised of wood packaging such as pallets and crates. It is estimated that 348 million pallets are produced each year and that there are 1.9 billion in use at any given time throughout the United States (Buehlmann, Bumgardner and Fluharty, 2009). Several sources have estimated that 90%-95% of these are wooden pallets (Corinne Kator, 2016) (Trebilcock, 2013) (White and Hamner, 2005). The manufacturing of pallets consumes more hardwood lumber than flooring, furniture, millwork, and cabinets combined (Johnson and Caldwell, 2014). Once pallets reach the end of their useful service lives, a large number of them are disposed of in landfills. Researchers at Virginia Tech investigated this in 1995 and 1998, and they found that pallets made up 1.5% and 2.8% of all MSW landfilled, respectively (Bush, Araman and Corr, 2001).

However, landfilling pallets is generally avoidable due to the fact that they are highly repairable. The stringer and deckboard components of pallets are replaceable. Alternatively, they can be dismantled into their individual components, and then used in the repair of other pallets. This practice is becoming more popular, and the number of pallets sent to repair firms increased from 143 million in 1995 to 326 million in 2011 but then declined to 235 million in 2016 (Bush and Araman, 2013). Many pallets still end up landfilled, but even they can be recovered if they are kept separate from other types of waste and diverted to a wood waste recovery area. In fact, this practice is prevalent; there were 32 million pallets recovered at MSW landfills in 1995 and 22 million in 1998 (Bush, Araman and Corr, 2001). Landfills that recover wooden pallets indicate a wide variety of uses: giving them away to residents, using them "as-is" for operations, grinding them into mulch to be sold or given away, used as material for composting or for use within the facility as road base or daily cover. Keeping pallets out of landfills helps to reduce the demand for virgin pallet lumber and to preserve landfill space while also generating economic activity.

3.2 Experimental

This research utilized a 19-item questionnaire that was developed to help collect information about waste management from municipal solid waste (MSW) facilities in the United States for the year 2016. Question types consisted of numerical responses, open-ended questions, closed-ended multiple choice questions, and partially closed-ended questions containing an "other" option.

A mailed questionnaire with the option to complete it online was chosen as the main method of data collection. This method provided the ability to reach a diverse sample population at a low cost while still allowing time for the respondents to gather the necessary data to fill out the questionnaire (Dillman, 2009). The design and content of the questionnaire were modeled after previous surveys conducted by researchers at Virginia Tech in 1995 and 1998 which investigated the same primary research topics. However, the wording and style of several of the questions were changed to be compatible with the online survey and/or in an attempt to improve the analysis based upon the recommendations for future research provided by the respondents of the previous surveys. The structure of this questionnaire followed a sequential development; it started by asking general questions about facility characteristics, waste received and landfilled, and tipping fees then moved onto the landfilling and recovery of wood and wood pallets.

When deciding where to mail this questionnaire, MSW facility selection was based upon the state legislation of landfill classifications through information largely available in the public domain. Because most landfills are required to have permits, databases of permitted facilities are commonly published online by state regulatory agencies. Facility classification methodology can vary from state to state depending on the respective regulations around facility operating permit issuance. Thus, it was important to first delineate each state's classification scheme in order to determine which facilities to include in the sample population. Facilities that were included in this research study were chosen based on their matching the general description of a municipal solid waste facility as defined by the United States Environmental Protection Agency (USEPA). Hawaii and Alaska were not included in this research study due to the fact that their population characteristics were inconsistent with the continental United States (Bush, Araman and Corr, 2001). Before removing the facilities that indicated that they did not receive MSW from the list, the sample population consisted of 1,385 facilities.

The questionnaires were mailed in June of 2017 through the physical mail system to addresses complied from state population databases along with the cover letter and prepaid, addressed return envelopes. A link was provided on the cover letter that offered the recipients the opportunity to fill out the survey through Qualtrics (Provo, UT, USA), an access-restricted, online-survey, software company. A temporary website was created at www.vtlandfillsurvey.org to provide an easily accessible link to the Qualtrics survey. Each questionnaire had a unique identifier that allowed the recipients to gain one-time access to the online survey. A postcard was sent 10 business days after the initial questionnaire was mailed, reminding the facilities to fill out the survey. Ten days after mailing the postcard, a second copy of the same questionnaire was sent to the facilities who had not yet returned a response. If email addresses were able to be found for any of the non-responding facilities, two reminder emails were sent out using MailChimp’s email distribution system (Atlanta, GA, USA) after the second mailed questionnaire.

Facilities were grouped into four regions, using the methodology of the U.S. Census Bureau, to help provide a higher level of detail and to allow comparison to the research studies from previous years (Table 7). To extrapolate the facility results into a national estimate, several steps were taken to analyze the data. The mean facility tonnage was based only on the facilities that responded to both question number two and four. This mean was then multiplied by the total number of facilities to determine a national estimate. Each of the individual categories question four were then summed together and divided by the total waste accepted by the respondents of question four to find the percentage of waste by category for all facilities. These percentages were applied to the national total waste estimate that had been calculated to determine total waste by category. These sums for each category were then compared by region to determine the percentage of waste per category for which each region was responsible. The percentage that each region made up of the total for all regions was multiplied by the total waste for each category to determine the amount of waste per category by region. This same methodology was followed for questions nine and eleven.

To determine the amount of wood landfilled and recovered by category, the same methodology was followed. All response in category of waste were added together, and the percentage of the total wood landfilled or recovered by the respondents was determined by dividing the sum total of categories by a particular category, for example pallets landfilled. To determine the national total, the percentage of each category was multiplied by the total wood waste landfilled or recovered reported in question four.

Table 7 U.S. Census Bureau regional groupings of states.

West	Midwest	South	Northeast
Arizona	Illinois	Alabama	Maine
California	Indiana	Arkansas	Vermont
Colorado	Iowa	Georgia	New Hampshire
Idaho	Kansas	Kentucky	Pennsylvania
Montana	Michigan	Louisiana	Massachusetts
Nevada	Minnesota	Mississippi	New Jersey
Oregon	Missouri	North Carolina	Connecticut
Utah	Nebraska	South Carolina	Rhode Island
Washington	North Dakota	Tennessee	New York
Wyoming	Ohio	Virginia	Delaware
New Mexico	South Dakota	West Virginia	
	Wisconsin	Maryland	
		Florida	
		Oklahoma	
		Texas	

3.3 Results and Discussion

MSW Response Rate and Distribution

Overall, there were 1,385 MSW facilities surveyed, but 42 of the facilities indicated that they did not accept MSW. The adjusted population size was 1,343; the breakdown shows 106 in the Northeast, 525 in the South, 327 in the Midwest, and 385 in the West (Table 8). The questionnaire received 173 responses resulting in a 12.9% response rate.

Table 8 Adjusted population size and response rate for MSW facilities surveyed in each region.

Region	Number of Facilities Surveyed	Number of Respondents	Percent Response
All Regions	1,343	173	12.9%
Northeast	106	15	14.2%
South	525	65	12.4%
Midwest	327	38	11.6%
West	385	55	14.3%

One simple test for skewness is to compare the median to the mean. With a mean of 185,077 tons and a median of 71,690 tons, the data is right-tail skewed. Similar distribution skewnesses were found in nearly every question's responses except for the question regarding tipping fees. This pattern indicates that there are more small facilities than large ones. Literature supports this hypothesis, and in 2016, the Environmental Research and Education Foundation (EREF) found that 33% of landfills receive the majority of all waste (Environmental Research and Education Foundation, 2013).

After the survey was completed, the nonresponding facilities were contacted to see if there was a bias among the facilities that completed the survey compared to those that didn't. Faciliites were asked if the majority of the waste they received was MSW and to report the total tonnage of MSW received in 2016. When using the Wilcoxon Signed Rank Test, there was a p-value of 0.55, which indicates that there was no significant response bias.

Mean Waste Received per Facility and Total Tonnage

The mean amount of waste received at each MSW facility in 2016 was 185,077 tons. This is an increase from the Virginia Tech studies of 1995 and 1998, which estimated 103,000 tons and 138,400 tons, respectively (Figure 8) (Corr *et al.*, 2000).

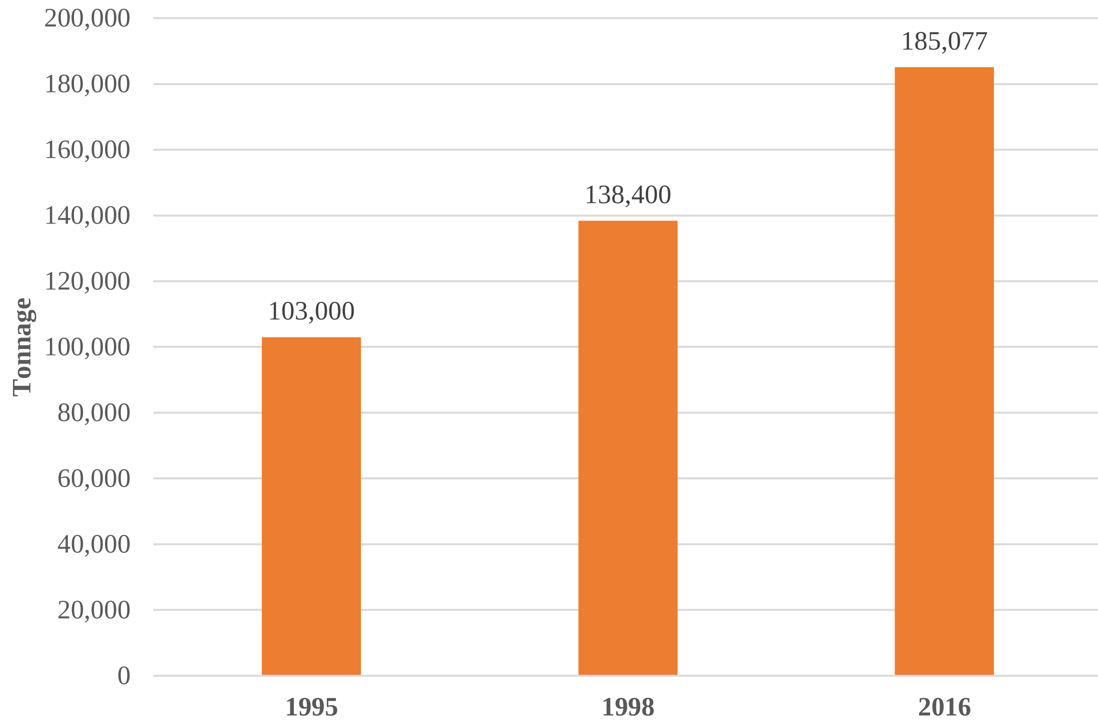

Figure 8 Mean tonnage of waste received at MSW facilities in 1995, 1998 (Corr et al.), and 2016.

In 1976, the RCRA made building landfills more capital intensive and subjected them to more regulation. In 1993, amendments were made to the Resource Conservation and Recovery Act Subtitle D which required all active municipal solid waste landfills to make expensive technological improvements to their facilities or exit the market by 1995 (Tomarelli, 2008). In response, solid waste management companies started to build “mega-dumps” which utilized economies of scale for larger construction, longer lifespan, and greater service areas to reduce costs (Palmer, 2011). Facilities that were previously unregulated often did not want to transition to make their facility meet the new requirements. This is shown by the decreasing number of landfills in the United States which went from 2,829 in 1995 to 1,669 in 1998 and to 1,343 MSW facilities in 2016 (Corr *et al.*, 2000). While the number of MSW facilities in the US has decreased since 1995, the amount of waste generated since 1960 has generally gone up (Figure 9). This means that each facility is now capturing a larger portion of the total amount of waste generated (United States Environmental Protection Agency 2016).

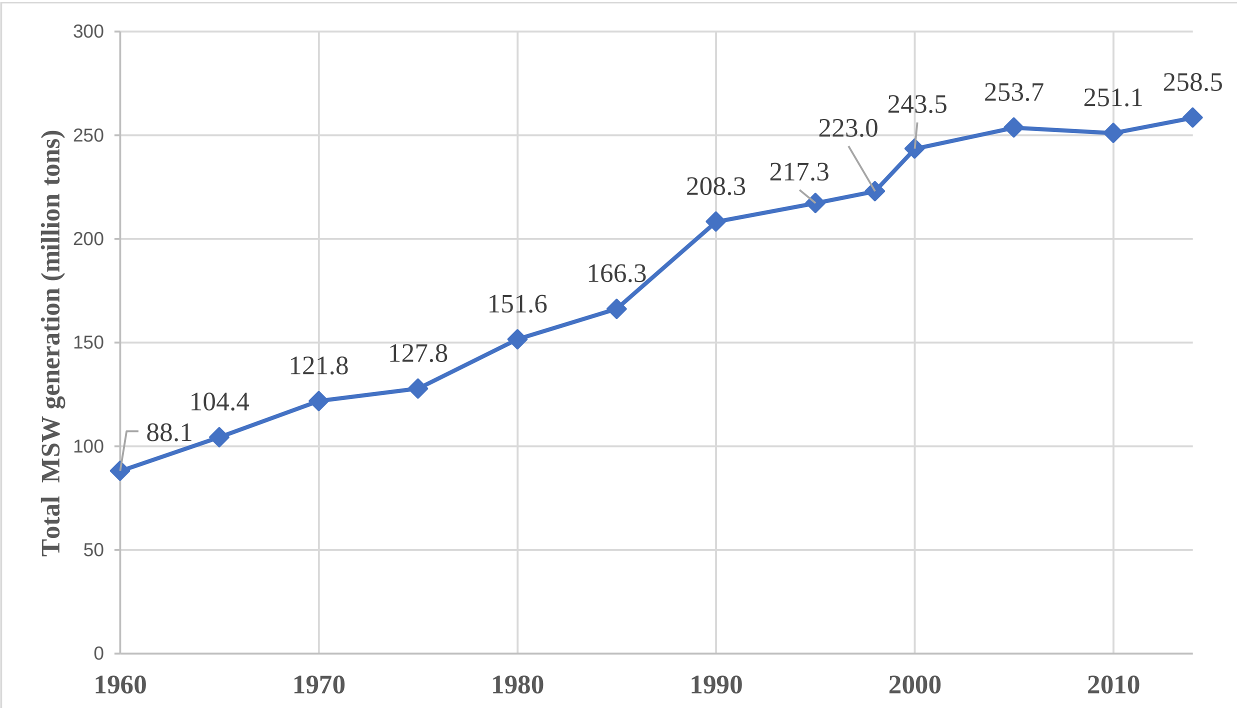

Figure 9 United States Environmental Protection Agency total MSW generation from 1960 to 2014 (Source: United States Environmental Protection Agency 2016).

When analyzed regionally, facilities in the South received a mean of 235,228 tons which was over 9% more waste than the facilities in the Northeast which received the second highest amount of waste at 215,708 tons. Facilities in the West received a mean of 156,403 tons of waste, and facilities in the Midwest received the lowest amount of waste with a mean of 126,556 tons (Table 9). Due to the distribution of the data, non-parametric statistics were used to test for significant differences between regions. When using the Steel-Dwass nonparametric multiple comparison for all pairs, significant differences were found to exist between the South and the Midwest with a p-value of 0.0235 and between the South and the West with a p-value of 0.0135 using a 95% confidence interval (Appendix A).

In both 1995 and 1998, the Midwest had the lowest amount of waste received per facility at 73,200 tons and 109,500 tons, respectively. Facilities in the South received the most waste out of all of the regions in 1995 and 2016, while facilities in the Northeast received the most waste in 1998.

Table 9 Year to year comparison of mean tonnage of waste received per MSW facility by region for 1995, 1998, and 2016.

	1995 (Tonnage)	1998 (Tonnage)	2016 (Tonnage)
All Regions	103,300	138,400	185,007
West	107,100	145,400	156,403
Midwest	73,200	109,500	126,556
Northeast	97,500	182,000	215,708
South	119,000	151,600	235,228

Facilities in all regions saw an increase in the mean tonnage of MSW received from 1995 to 1998 and from 1998 to 2016. However, the rate of increase varied regionally possibly due to the differences in economic conditions, living standards, urbanization, and population (Kawai and Tasaki, 2015). Also, every state has different landfill regulations, available space, and varied public response to the construction of new landfill sites. In 2011, Slate writer, Brian Palmer, found that Arkansas reported that it has over six hundred years of landfill capacity available while Rhode Island and Massachusetts reported having less than twelve years capacity (Palmer, 2011). Smaller, highly populated states do not have as much land available, and they often resort to shipping their waste across state lines. Alternatively, states in some regions, like the South, have plenty of available landfill space, and they import waste from other states. For example, Virginia has private sanitary landfills that accepted several million tons of waste from other states in 2006 (Figure 10). Shipping waste away from the source results in less being recorded where it was generated and more being recorded in the region that received it. In 2013, it is estimated that about 90% of the waste received at landfills was generated within the state, and the remaining 10% was shipped across state lines (Environmental Research and Education Foundation, 2013).

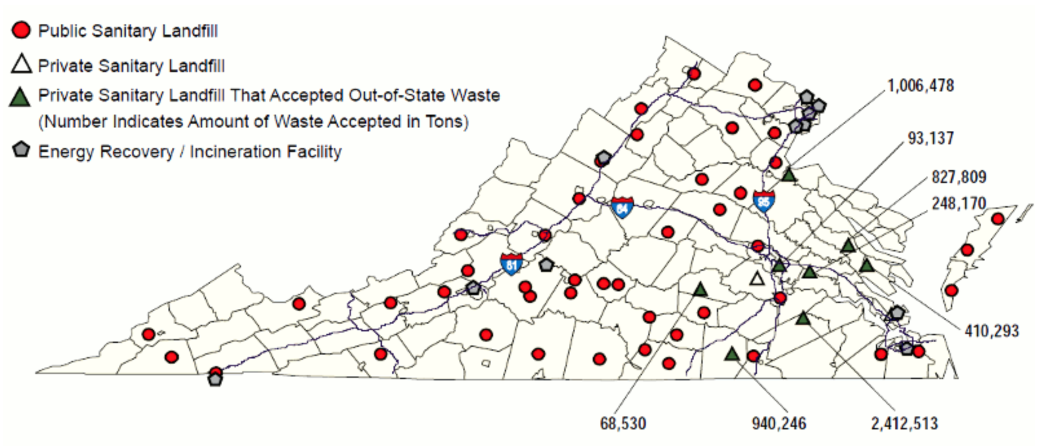

Figure 10 Sanitary Landfills and Incinerators (2008) and Out-of-State Waste Accepted at Private Sanitary Landfills (2007) Source: Joint Legislative Audit and Review Commission, Figure 2 (Commission Report – September 8, 2008).

The total estimate of waste received at MSW landfills nationally in this study was 248,600,000 tons, representing an increase from 1998 (238,960,000 tons) but a decrease from 1995 (293,010,000 tons) (Table 10).

Table 10 Virginia Tech estimates of total waste received at MSW facilities in the United States along with number of MSW facilities in 1995, 1998, (Corr et al 2000) and 2016.

	1995	1998	2016
Number of MSW Facilities	2,829	1,669	1,343
Virginia Tech (Total Waste Received) (Tonnage)	293,010,000	238,960,000	248,600,000

The 248.6 million tons of total waste landfilled in 2016 is close to the US EPA's most recent estimate of 258.5 million tons in 2014, although the two studies used different methodologies and are not directly comparable. The results of the Virginia Tech and EPA methodologies were also similar in 1998, with the EPA estimating 223 million tons and the Virginia Tech study estimating just under 239 million tons. However, in 1995, the EPA's estimate of 217 million tons was much lower than Virginia Tech's estimate of 293 million tons.

It also needs to be mentioned that while this study utilized a "bottom-up" approach, collecting responses at the facility level, the EPA utilized a materials flow methodology that relied on gathering data from manufacturing, disposal, and recovery practices to estimate the amount of waste generated, landfilled, and recovered. While the proximity of the two values may indicate that both methodologies are fairly comparable, it is important to note that this study was not capable of estimating for any waste that did not physically arrive at landfills. Alternatively, the EPA's estimates account for all of the waste generated in the United States regardless of whether it actually arrived at a MSW landfill or not. Despite counting significant amounts of waste that was recycled prior to arriving at landfills in their estimate for total waste generated, this value is similar to estimates provided by previous Virginia Tech studies. Several factors can lead to the variance between the values, however the most prominent may be that intermingling of waste streams. If C&D waste is ending up at MSW facilities, then it would inflate the value reported by landfills without being accounted for by the EPA.

Estimates of total waste generated is also provided by other organizations such as Earth Engineering Center (EEC) at Columbia University and the Environmental Research and Education Foundation (EREF). These organizations utilized a method where facilities or state agencies are surveyed directly, and their results showed an estimated amount of waste generated that was approximately 100 million tons higher than the EPA estimate in the comparable years. For example, the Environmental Research and Education Foundation (EREF) estimated that 347 million tons of MSW were generated in 2013, and the Earth Engineering Center (EEC) of Columbia University estimated that over 388 million tons of MSW were generated in 2011 (Environmental Research and Education Foundation, 2013) (Van Haaren, Themelis and Goldstein, 2010). There are several theories for why there is a discrepancy between the EPA estimates and other studies. Themelis et al. suggests that the reason for the differing estimates may be caused by the moisture content of waste, imported packaging that is difficult to account for, counterfeit goods, or non-MSW being received at MSW facilities (Themelis, 2014).

Received Waste by Category

MSW facilities were asked to provide a breakdown of the types of waste received. The questionnaire included four options for types of waste received: (1) wood landfilled, (2) normal waste landfilled, (3) wood recovered, and (4) normal waste recovered. Landfilled normal waste includes all types of MSW that are not either wood or recovered normal waste. "Recovered waste" is defined as any waste accepted by the facility that did not get buried directly in the landfill which implies that they instead went through a recovery operation such as recycling, incineration, or composting. "Wood landfilled" is all wood, treated wood, wood products, woody yard waste, pallets, wooden packaging and crates, or wood from the construction and destruction of structures that was buried in the landfill. “Wood recovered” encompasses all the same categories as “wood landfilled” (except treated wood), but the wood went through a recovery option instead of being buried. Wood landfilled and wood recovered utilized the mean tonnage received at facilities in each region. The total national estimates for tonnage in each category were calculated by the percentage that the category made up of the total waste. The results to this question are presented in Table 11.

Table 11 Mean waste and total national waste received at each MSW facility by category. Including the percent, by category, of total waste received at landfills.

Waste Category	Mean Waste Received per Facility (Tonnage)	Total National Waste Received at Landfills (Tonnage)	Percent of Total National Waste Received at Landfills
Wood Landfilled	14,896	20,006,000	8.05%
Normal Waste Landfilled	156,994	210,842,000	84.83%
Wood Recovered	7,590	10,193,000	4.10%
Normal Recovered	5,598	7,517,000	3.02%

Landfilled Normal Waste

Overall, the amount of normal waste landfilled made up the largest portion of total waste received at 84.8%. Each facility received a mean of 156,994 tons (Table 11). This is a trend that was expected when surveying MSW facilities that primarily manage landfills receiving unsorted waste from dump trucks. If the scope had been broadened to include all waste received at transfer stations, Material Recovery Facilities (MRFs), composting facilities, and waste-to-energy facilities, it is likely to have shown a smaller portion of all waste being landfilled.

Regionally, the South landfilled the largest tonnage of normal waste per facility with a mean of 191,409 tons per facility. The West had the lowest, at 118,572 tons, while the Midwest was slightly higher at 119,163 tons (Table 12). The Northeast landfilled the second largest amount per facility at 176,907 tons. As a regional total, the South had the highest amount of normal waste at 89.4 million tons while the West had the second highest amount with 63.1 million tons. The Midwest and West landfilled 32.9 million and 25.4 million tons of normal waste, respectively.

Table 12 Mean normal waste landfilled per MSW facility in 2016 by region.

	Mean Normal Waste Landfilled per Facility (Tonnage)	**Total Normal Waste Landfilled (Tonnage)**
All Regions	156,994	210,842,000
Midwest	119,163	32,912,000
South	191,409	89,443,000
Northeast	176,907	25,431,000
West	118,572	63,056,000

The estimate for the total national landfilled normal waste in 2016 was 210.8 million tons. In 2014, the EPA estimated that approximately 258 million tons of MSW were generated. Of this amount, 136 million tons were landfilled, 89 million tons were recycled or composted, and the remaining 33 million tons were combusted (United States Environmental Protection Agency, 2016). Using these estimates, only 52.6% of normal waste was landfilled. This is significantly different from the results of this study, which estimates that 84.8% of waste arriving at MSW facilities is landfilled. However, the EPA methodology takes into account **all** waste generated; this study only investigated waste that arrived at landfills. Much of the EPA's estimated total waste is actually diverted from the landfill prior to arrival. Another cause of this inflation may be that this study did not include an "other" option for separating out waste that is not MSW but that the surveyed facilities still processed and landfilled. "Other" types of waste includes fly ash and treated sewage both of which the EPA would not consider in their estimates of MSW generated, but these types of waste could have been included in responses from the facilities in this study. This happens because many facilities are permitted to accept a wide variety of waste including, but not limited to, MSW. However, the "other" option was not included in order to keep this questionnaire consistent with previous Virginia Tech surveys.

Regionally, the West landfilled the largest tonnage of normal waste (69.6 million tons), followed by the Midwest (68.2 million tons), and the South (67.4 million tons). The least amount was waste was landfilled by the Northeast (55.5 million tons.) (Table 12).

Normal Waste Recovered

Normal waste recovered includes any waste that arrives at a landfill but is not directly buried – instead it is recycled, composted, or incinerated. It is estimated that each facility recovered a mean of 5,598 tons of normal waste (Table 13). Regionally, facilities in the South recovered the highest mean normal waste per facility with a mean of 6,609 tons. The Midwest had the lowest mean of normal waste recovered with 2,287 tons per facility. Facilities in the West and the Northeast reported recovering a mean of 5,681 tons and 5,396 tons of normal waste, respectively.

A total of 7.5 million tons of normal waste were recovered at MSW facilities within the United States in 2016. Regionally, the South and the West captured over 82% of recovered normal waste at 3.1 and 3.0 million tons, respectively. The Northeast and the Midwest recovered 775,740 and 631,826 tons, respectively.

Table 13 Mean normal waste recovered per MSW facility by region.

Region	Mean Normal Waste Recovered per Facility (Tonnage)	Total Normal Waste Recovered (Tonnage)
All Regions	5,598	7,517,000
Midwest	2,287	631,826
South	6,609	3,089,000
Northeast	5,396	775,740
West	5,681	3,021,000

The results show a national total of just over 7.5 million tons of normal waste recovered which is 3.0% of all waste received at MSW landfills in 2016 (Table 11). This number is significantly lower than the EPA's estimate of 89 million tons of recovered MSW with an additional 33 million tons combusted (United States Environmental Protection Agency 2016). This is likely because questionnaires were not sent to Material Recovery Facilities (MRF) or transfer stations. Transfer stations often sort and send waste to MRFs. A MRF is a special type of transfer station that separates, processes, and consolidates recyclable materials for shipment to recovery facilities instead of landfills or other disposal sites (U.S. Environmental Protection Agency, 2002). Because this study only surveyed two types of waste management facilities that primarily function as landfills, it recognizes only a small portion of the overall recycling activity that is occurring within the waste management industry. A large amount of recovered materials were not studied, and the overall amount of waste MSW and C&D waste generated would be higher that the estimate for total wood received at landfills which is the value this study found.

Wood Landfilled

Landfilled wood waste includes all types of wood, treated wood, wood products, woody yard waste, pallets, wooden packaging, crates, and wood received at MSW facilities from the demolition of structures. Overall, approximately 86.3% of MSW facilities accepted wood waste for landfilling in 2016. The Midwest, with 96.8% of their facilities accepting wood waste for landfilling, had the fewest restrictions while the Northeast, with only 75.0% of their facilities accepting wood waste, had the most stringent (Table 14).

Table 14 Percentage of facilities accepting wood waste for landfilling by region.

Region	Percent of Facilities Accepting Wood for Landfilling
All Regions	86.30%
Midwest	96.77%
South	89.47%
Northeast	75.00%
West	82.46%

The mean amount of wood waste landfilled per facility was 14,896 tons (Table 15). This is equivalent to approximately 8% of all waste (Table 16). When the data is analyzed by region, landfills in the South, with a mean of 32,250 tons of wood waste landfilled per facility (which is 13.2% of all MSW received in the region), had the greatest amount of wood waste landfilled per facility. Facilities in the South received more average waste than any other region in 2016, and the same trend holds for wood landfilled. The South also had the greatest proportion of all waste received being landfilled wood waste. The West had the second highest mean of wood waste landfilled with 5,974 tons, and facilities in the Northeast received a slightly lower mean of 5,960 tons. Facilities in the Midwest landfilled a mean of 3,610 tons of wood waste, which made up just 2.9% of all waste received.

Table 15 Mean wood waste landfilled per MSW facility in 1995, 1998, and 2016.

	Mean Wood Waste Landfilled per Facility (Tonnage)		
	1995	**1998**	**2016**
All Regions	9,980	11,820	14,896
Midwest	5,939	7,600	3,610
South	11,127	14,700	32,250
Northeast	7,110	21,650	5,960
West	12,648	9,500	5,974

Table 16 Percent of overall waste received that landfilled wood waste for 1995, 1998, and 2016.

	Percent of the overall Waste Received that was Landfilled Wood		
	1995	**1998**	**2016**
All Regions	7.30%	10.90%	8.04%
Midwest	8.00%	8.90%	2.85%
South	6.00%	11.30%	13.16%
Northeast	6.60%	11.50%	3.15%
West	7.30%	12.20%	4.28%

The mean tonnage of wood received per facility in 2016 was 14,896 tons. This was a 26.0% increase from the 1998 mean of 11,820 tons (Table 15). Despite the overall average increasing, all regions, except the South, experienced a large decrease in the mean amount of wood waste landfilled per facility. Out of the 20 facilities that landfill the most wood waste, 10 were in the South. These results indicate that the typical facility in the South receives more waste overall, and that they landfill the greatest proportion of it. However, these results were shown not to be statistically significant, by performing a Steel-Dwass nonparametric multiple comparison for all pairs, due to the large range of the tonnages that facilities accepted (Appendix A).

When compared to the historical values, the amount of wood waste landfilled as a proportion of total waste received at each facility has decreased from 1998 in all regions except the South (Table 16). The mean percentage of national total waste received per facility that was landfilled wood waste dropped from 10.9% in 1998 to 8.0% in 2016. The Northeast saw the greatest reduction; their mean percentage dropped from 11.5% in 1998 to 3.2% in 2016.

Nationally, the total amount of wood waste landfilled in 2016 was approximately 20.0 million tons; a decrease from the estimates of 28.2 million in 1995 and 20.8 million in 1998 (Table 17). These results indicate that the overall amount of wood waste being landfilled in the continental United States has been trending downwards since 1995, and less wood waste is being generated overall.

Table 17 Total wood waste landfilled by region at MSW facilities in 1995, 1998, and 2016

	Total Wood Waste Landfilled (Tonnage)		
	1995	**1998**	**2016**
All Regions	28,220,000	20,840,000	20,006,000
Midwest	3,154,000	3,025,000	997,112
South	11,780,000	10,422,000	15,070,000
Northeast	3,107,000	3,659,000	856,806
West	10,179,000	3,734,000	3,082,000

Regionally, the South landfilled 15.1 million tons of wood waste; this was 3.9 times higher than the West which was the region with the second most amount of wood waste landfilled at just under 3.1 million tons (Table 17). In each of the past studies, the South landfilled the highest amount of wood, and it was the only region that had an increase in the amount of wood landfilled from 1998 to 2016. As previously discussed, the South contains some of the largest MSW facilities in the country, and it also has the highest number of landfills when compared to the other regions which is why it has landfilled over 75% of the total national wood waste.

The EPA estimated that 8.1% of the 136 million tons of landfilled MSW in 2014 was wood waste. Their total of 11 million tons is lower than the estimate of this study by approximately 9 million tons. One possible reason for this is that the EPA separates their estimates for wood waste from yard trimmings. When their estimates for the categories of yard trimmings and wood waste are combined, the total is approximately 21.8 million tons which is much closer to this study's estimates (United States Environmental Protection Agency, 2015). When compared to the Virginia Tech studies of previous years, the total 20.0 million tons of wood waste landfilled in 2016 shows a slight decrease from the previous estimates of 28.2 million tons in 1995 and 20.8 million tons in 1998 (Table 17).

MSW Tipping Fees

Table 18 shows the mean tipping fees per ton, by region for normal MSW, recovered wood and brush, and recovered pallets. The overall mean tipping fee for normal MSW in 2016 was $49.92 per ton. Facilities in the Northeast charged the highest rates at $61.83 per ton. This is likely because available landfill space in the Northeast is at a premium. The Northeast also has the lowest tipping fees for recovered wood and brush at $23.94 per ton. Because of the desirability of keeping waste out of the landfills when space is limited, it makes sense that facilities in this region promote recovery. This study found that the Northeast region has the lowest percentage of facilities accepting wood waste for landfilling.

Table 18 Mean tipping fees per ton by region for Normal MSW, recovered Wood and Brush, and Recovered Pallets in US Dollars.

	Normal MSW ($/Ton)	Recovered Wood and Brush ($/Ton)	Recovered Pallets ($/Ton)
All Regions	$49.92	$30.73	$33.62
Midwest	$46.59	$27.07	$29.00
South	$47.23	$34.32	$36.36
Northeast	$61.83	$23.94	$41.00
West	$50.96	$29.98	$30.21

When compared to historical values that have been adjusted to present value using the Consumer Price Index (CPI) in January, 2016, the mean price of recovered wood and brush decreased from $35.97 per ton in 1998 to $30.73 per ton in 2016 (Table 19). The South had the highest tipping fees for recovered wood and brush. A possible explanation for this may be that there is plenty of space in landfills in this region; therefore, they do not need to incentivize recovery. The reason that mean tipping fees for recovered wood and brush are higher than the mean tipping fees for recovered pallets in all regions is because many facilities do not have special rates for pallets, and thus they end up with the same rate as normal waste.

Table 19 Mean tipping fees in USD per ton for recovered wood and brush received at MSW facilities in 1995,1998, and 2016. Historical values were adjusted using the consumer price index from January 2016.

	Mean Tipping Fee for Recovered Wood and Brush at MSW Facilities ($/Ton)		
	1995	1998	2016
All Regions	$36.78	$35.97	$30.73
Midwest	$29.48	$33.89	$27.07
South	$37.57	$35.94	$34.32
Northeast	$51.17	$49.53	$23.94
West	$31.02	$33.19	$29.98

Wood Landfilled by Category

The MSW facilities which indicated, in question four, that they landfilled wood waste were asked to estimate the breakdown of all wood waste landfilled into six different categories including: pallets, crates, construction related wood, treated wood, woody yard waste, and an "other" category meant for any wood waste received that could not be included in the other five categories. Of the 86.3% of facilities that landfilled wood waste, the mean tonnage of wood waste landfilled was 14,896 tons. The mean tonnage of each category per facility is presented in (Table 20).

Table 20 Mean tonnage and percentage of wood waste landfilled by category per MSW facility in 2016.

	Percentage of Wood Waste Landfilled	Mean Tons of Wood Waste Landfilled
Pallets	1.80%	267
Crates	2.74%	407
Construction Related Wood	55.22%	8,225
Treated Wood	17.40%	2,591
Yard Waste	15.8%	2,354
Other	7.05%	1,050

Overall, construction related wood made up the greatest portion of wood waste landfilled. Each facility landfilled a mean of 8,225 tons, which is equivalent to 55.2% of all wood waste landfilled. Regionally, the South and the Northeast had the highest amounts of this type of wood waste with 18,326 tons and 5,070 tons per facility, respectively (Table 21). The Midwest and the West reported lower values in this category of wood waste at 2,173 tons and 1,715 tons per facility, respectively. This highlights one of the common problems with attempting to quantify waste streams. It is possible that the construction related wood waste being reported by MSW facilities should be classified as Construction and Demolition (C&D) waste. Theoretically, this waste should be disposed of at different facilities or least quantified separately. While this does not cause a problem in methodologies that utilize facility-based data, it may be one of the main reasons that many of this study's estimates do not agree with the EPA estimates. A material flows method for MSW would not take C&D waste into account, and this mixing of waste streams could explain why several estimates from surveying the landfills directly were higher. The mixed nature of construction related debris makes it difficult to sort and process and/or it may not be as convenient for contractors to take it to a C&D facility.

Treated wood waste makes up the second largest portion of all wood waste landfilled with the facilities surveyed landfilling a mean of 2,571 tons per facility (Table 21). The South, with a mean of 5,742 tons per facility, was much higher than the other regions. Treated wood poses a challenge for some landfills because it is generally undesirable to have treated wood in mulch piles. While it is not classified as hazardous waste, many states have separate disposal sites for treated wood and prohibit the open burning of it (Connectictut Department of Energy and Environmental Protection 2017).

The mean tonnage for yard waste landfilled in all regions was 2,354 tons per facility. This was highest in the South and the West with their facilities reporting mean of 4,423 tons and 2,370 tons per facility, respectively. This is a stark contrast to the Northeast and the Midwest which reported a mean of 70 and 69 tons per facility, respectively. Regions-with a lack of landfill space often develop curbside pickup programs to help divert this type of waste from being landfilled. Woody yard waste should be relatively easy to recover because it usually lacks metal fasteners and contaminants, so it could represent an opportunity to divert more wood waste from landfills.

Table 21 Regional breakdown of tons of wood waste per MSW facility that landfilled wood in 2016.

Waste Type	All Regions	Midwest	South	Northeast	West
Pallets	267	190	513	186	37
Crates	407	182	817	149	164
Construction Wood	8,225	2,173	18,326	5,070	1,715
Treated Wood	2,591	567	5,742	215	1,275
Yard Waste	2,354	69	4,423	70	2,370
Other	1,050	429	2,373	271	233

Participants were also provided an "Other" category to account for any wood waste that was not included in one of the other categories. This "Other" category included wood products such as furniture and wood from various types of projects and activities. Facilities tracking wood waste in the South indicated that they landfilled a mean of 2,373 tons of "other" wood waste. Facilities in the Midwest, Northeast, and West reported much lower mean tonnages. Despite this, the tonnage of "other" wood waste was still higher than the pallets and crates categories of wood landfilled.

Overall, 75.8% of all MSW facilities indicated that they accepted pallets for landfilling in 2016. Over 90.3% facilities in the Midwest indicated that they landfilled pallets. This was the highest of any region. Conversely, only 66.7% of facilities in the Northeast indicated that they landfilled pallets (Table 22). The number of facilities landfilling pallets increased from 67.9% in 1995 to 83.7% 1998 but decreased to 77.18% by 2016. The increase from 1995 to 1998 could be explained by the enhanced facility requirements that the RCRA implemented in that time period.

Table 22 Percentage of MSW facilities accepting pallets for landfilling in 2016 by region.

	Percentage of MSW Facilities Accepting Pallets for Landfilling		
	1995	**1998**	**2016**
All Regions	67.90%	83.70%	75.83%
Midwest	71.00%	86.80%	90.32%
South	63.60%	83.80%	76.79%
Northeast	55.90%	67.40%	66.70%
West	77.30%	86.10%	77.78%

Facilities that did not accept pallets for landfilling were given the opportunity, on the questionnaire, to explain why they do not or cannot. Respondents commonly indicated that they separate pallets to send them to a recovery area where they can be ground up, which is a desirable result. Several states, such as North Carolina, have bans on landfilling pallets. Grinding up the pallets saves landfill space, and some facilities indicated that by mixing it with other materials, such as bio-waste coming from the waste treatment plant, they achieve 40% greater compaction.

Each MSW facility that indicated they landfilled wood waste reported a mean of 267 tons of pallets per facility in 2016 (Table 23). Regionally, the South landfilled the highest mean tonnage of pallets per facility in 2016 at 513 tons. This was a decrease from the 1998 estimate of 1,535 tons and the 810 tons in 1995. The mean tonnage of landfilled pallets per facility in the South was 170% higher than the mean tonnage reported by facilities in the Midwest, which was the region with the second highest mean tonnage of pallets landfilled. Using Steel-Dwass nonparametric comparisons for all pairs, it can be seen that facilities in the South have a significantly higher statistical probability of landfilling more pallets than both the West and the Northeast at 95% confidence level with a p-values of 0.0185 and 0.0129, respectively (Appendix A).

When compared to the results of previous Virginia Tech studies, 267 tons of pallets landfilled per facility is a 78.9% decrease from the 1,269 tons landfilled per facility in 1995 and a 76.9% decrease from the 1,158 tons of pallets landfilled in 1998. Facilities in all regions saw large decreases in the mean tonnage of pallets landfilled compared to the previous studies (Table 23).

Table 23 Mean tonnage of pallets landfilled per facility in 1995, 1998, and 2016 by region.

	Mean Amount of Pallets Landfilled per MSW Facility by Region (Tonnage)		
	1995	**1998**	**2016**
All Regions	1,269	1,158	267
Midwest	1,322	663	190
South	810	1,535	513
Northeast	961	1,354	186
West	1,357	949	37

There were 13,095,000 pallets landfilled throughout the United States in 2016 (Table 24). MSW facilities in the South landfilled over 9.2 million pallets, which is equivalent to 70.8% of all pallets landfilled in the United States in 2016. The Midwest and the Northeast had the second and third highest concentrations at 2.0 million and 1.0 million pallets, respectively. The West landfilled just 753,379 which is equivalent to just 5.8% of all pallets landfilled nationally. Clearly the South landfills more pallets than any other region. There are several possible explanations for this. Firstly, the South has more landfills that are also larger on average. This means more wood pallets are flowing to them. Landfills in the South have abundant space and often import waste from outside states. This leads to more wood pallets being sent to them and also allows to keep low tipping fees for landfilling. These low tipping fees may deter customers from separating pallets from other waste before it is brought in. Regional differences in economic activity that generate pallets waste could also cause a large difference between regions. For example, there are high number of seaports in the South, which could lead to more pallet waste being generated in the transportation, loading, and unload of goods shipped in and out.

Table 24 Total number of pallets landfilled in the United States in 2016 at MSW facilities by region.

Total Number of Pallets Landfilled by Region			
	1995	**1998**	**2016**
All Regions	152,745,000	138,360,000	13,095,000
Midwest	26,490,000	28,910,000	2,032,000
South	90,215,000	40,180,000	9,274,000
Northeast	10,560,000	12,440,000	1,036,000
West	25,480,000	56,800,000	753,379

This represents a sizable decrease in the number of pallets landfilled since the previous surveys were conducted in 1995 and 1998. It was estimated that 152.8 million pallets were landfilled in 1995 and 138.4 million in 1998 (Table 24). The findings of the current study indicate that there has been a 90.5% decrease in the number of pallets being landfilled since 1998.

The decrease in the number of pallets landfilled can be attributed to several factors. During the challenging economic conditions brought about by the 2008 recession, businesses started looking for ways to save money. The amount companies were spending on purchasing pallets received increased awareness, thus reusing pallets, selling them to recyclers, and buying recycled pallets all became strategies to help companies save money within their supply chain. There was also a rapid increase in the total portion of retail sales being generated from e-commerce, rising from 0.6% in 1999 to 8.2% by the fourth quarter of 2016 (Federal Reserve Bank of St. Louis 2018). E-commerce sales have a different supply chain set up than traditional brick and mortar sales. Fewer pallets are required because the goods flow from the suppliers to the distribution centers and then directly to the customers by parcel shipment instead of being stored and moved about on palletized loads.

Because pallets can be sold to pallet recyclers, there may have been an increase in pallet "scavengers." Some of these recycling companies will accept as few as 100 pallets at a time, and they will sometimes even station a trailer at your facility for convenience. Also, as this study shows, more MSW facilities are choosing to operate their own pallet recovery programs than in previous years. This suggests that landfills now have a greater awareness of the potential for pallet recovery, and they would like to take advantage of the additional value that recovery can provide them. In addition, several states have implemented bans on landfilling wood or pallets since the previous 1998 study. For example, North Carolina no longer allows pallets to be landfilled, and Vermont has a ban on landfilling wood.

It has been several years since updated estimates of pallet production and national use rates have been created. The most recent estimate suggests that the number of pallets has increased from 411 million in 1995 to 508 million in 2016 (Gerber 2016). While there is an increase in the number of pallets produced, companies may be outsourcing pallet management to pallet rental companies, often referred to as pallet pooling firms. This leads to better control of the pallet supply chain because more pallets end up being recycled, reused, or refurbished thus staying out of landfills. CHEP and PECO were contacted to provide additional information regarding this analysis, but they declined to share proprietary data.

Another factor contributing to the decrease in landfilled pallets is the cultural shift towards a more intense emphasis on sustainability. This may have led to more pallet users taking the effort to separate pallets before bringing their waste to landfills. Overall, people are recognizing that pallets in nearly any condition still have value, and they can become a source of personal income or a cost savings within an organization. If pallets cannot be sold to pallet recyclers, such as in the case of small quantities or odd sizes of pallets, pallet recyclers recommend finding companies that produce mulch, looking on Craigslist to find pallet scavengers, or using old pallets in bonfires because of their low moisture content (Gruber Pallets 2017). Instead of being viewed as a disposable commodity, people are taking steps to extend the lives of pallets far beyond the purpose for which they were initially built. This can even include the use of discarded pallets for home improvement, crafting, or for reuse in new construction, such as wall paneling and bar seen at Highland Brewery in Asheville, North Carolina (Figure 11).

Figure 11 Example of pallet parts being used in new construction at Highland brewery in Asheville, North Carolina.

Participants were told at the beginning of the questionnaire that the category of “crates” includes boxes, barrels, baskets, carrier trays, chests, and reels. In 2016, the mean tonnage of crates landfilled per MSW facility was 407 tons (Table 21). Regionally, the South landfilled the most with a mean of 817 tons per facility. Facilities in the Northeast landfilled the lowest amount with a mean of 149 tons per facility. Facilities in the Midwest and the West landfilled 182 tons and 164 tons of crates per facility, respectively. The previous surveys did not ask the MSW facilities to directly describe the tonnage of crates being landfilled.

This study intended to investigate the overall amount of wood packaging going to landfills in the United States including pallets, crates, and other types of wooden packaging. The mean tonnage of wood packaging for all facilities was 674 tons. On a regional basis, the South landfilled the most wood packaging with 1,330 tons per facility while the West landfilled the lowest with a mean of 201 tons per facility (Table 25). However, it is interesting to note that the overall facilities landfilled 52.4% more crates than pallets. Because the previous surveys were not explicit as to whether crates should be included or not, it is possible that landfill managers attributed some crate disposal to the larger category of pallets. This also helps to explain why the total tonnage of pallets landfilled has decreased so dramatically since 1998.

Table 25 Mean tonnage of wood packaging landfilled per facility by region in 2016.

Pallet and Crates Landfilled per MSW Facility per Region (Tonnage)					
Type of Waste Landfilled	**All Regions**	**Midwest**	**South**	**Northeast**	**West**
Pallets	267	190	513	186	37
Crates	407	182	817	149	164
Wood Packaging Total	**674**	**372**	**1,330**	**335**	**201**

Nationally there were just under 1.8 million tons of wood packaging landfilled in 2016 (Table 26). The South landfilled the greatest amount of wood packaging at 641,418 tons. This was 76.8% higher than the Midwest, the region with the second highest value, at 110,181tons. Unlike pallets which have relatively standardized sizes and designs, there are a wide variety of crate designs and variations. This makes it impractical to attempt to quantify the number of crates being landfilled. But even if we assumed that all reported wood packaging waste consisted of 55lb pallets, the total number of pallets landfilled would only be about 32,993,953, which is still a 76.2% reduction from the 138 million pallets landfilled in 1998.

Table 26 National total amount of landfilled wood packaging.

Region	National Total of Landfilled Wood Packaging (Tonnage)
All Regions	907,333
Midwest	106,045
South	641,418
Northeast	49,689
West	110,181

Wood Recovery

Over 62.4% of MSW landfill facilities in the United States operated recovery areas in 2016, and an additional 5.1% plan on adding this capability within the next two years (Table 27). When compared to historical results, these findings show that the percentage of facilities operating recovery areas in each region has nearly doubled (

Table **28**). This is likely due to the fact that more facilities are recognizing the opportunity for monetary savings through wood recovery, and they are choosing to add the equipment, labor, and facility space necessary to recover wood. There is also more legislation requiring wood recovery. Also, since the total number of MSW facilities has decreased since 1998, it is possible that those remaining in operation were newer, larger, more sophisticated, and more likely to already have the necessary equipment for wood recovery.

Table 27 Percentage of MSW landfills operating recovery areas in 2016 and planning to add capability within the next two years by region

Percentage of MSW Facilities Operating Wood Recovery Areas		
Region	**Currently Operating**	**Plan to Add with Two Years**
All Regions	62.4%	5.1%
Midwest	55.2%	10.3%
South	68.4%	0.0%
Northeast	58.8%	5.9%
West	61.4%	7.0%

Table 28 Percent of facilities operating wood recovery areas in 1995, 1998, and 2016 by region

Percentage of MSW Facilities Operating Wood Recovery Areas (Historical)			
Region	**1995**	**1998**	**2016**
All Regions	37.9%	33.4%	62.4%
Midwest	30.8%	32.2%	55.2%
South	49.0%	49.0%	68.4%

Northeast	38.2%	45.5%	58.3%
West	27.0%	30.6%	61.4%

On average, MSW landfills recovered 7,589 tons of wood waste per facility in 2016 (Table 29). Facilities in the South recovered the most amount of wood with a mean of 14,513 tons per facility. The West had the second highest with a mean of 5,955 tons, while the Midwest and Northeast recovered 1,519 and 1,238 tons per facility, respectively. Historically, the overall mean tonnage of wood waste recovered per facility decreased by 51% from 1998. Additionally, every region except the South saw a decrease in the amount of wood recovered when compared to the previous studies.

Table 29 Mean tonnage of wood recovered per MSW facility for 1995, 1998, and 2016 by region.

Mean Amount of Wood Recovered per MSW Facility (Tonnage)			
Region	**1995**	**1998**	**2016**
All Regions	12,866	15,498	7,589
Midwest	21,536	35,037	1,519
South	3,418	5,748	14,513
Northeast	5,329	6,568	1,238
West	14,978	14,659	5,955

Overall, there were more than 10 million tons of wood recovered at MSW wood recovery facilities in 2016. This represents an increase from the estimate of 8.9 million tons in 1998 and only a slight decrease from the 10.3 million tons in 1995 (Table 30). The South was the only region that saw an increase in the tonnage of wood waste recovered, rising from 3.5 million tons in 1998 to nearly 6.9 million tons in 2016. Each of the other regions saw significant reductions in the amount of wood waste recovered when compared to the 1998 study.

Table 30 Total wood waste recovered per MSW recovery area in 1995, 1998, and 2016 by region.

Total Wood Recovered by Region (Tonnage)			
Region	**1995**	**1998**	**2016**
All Regions	10,320,000	8,932,000	10,019,000
Midwest	449,000	721,000	410,778

South	6,755,000	3,500,000	6,889,000
Northeast	730,000	506,000	156,311
West	2,386,000	4,205,000	2,737,000

When the total tonnage of wood recovered is taken in combination with the total tonnage wood landfilled, it can be seen that the overall amount of wood waste received at MSW landfills has increased slightly from 29.7 million in 1998 to 30.2 million tons in 2016 (Table 31). This has resulted in an increase in the proportion of total wood received at landfills that is recovered as opposed to landfilled.

Table 31 Total tonnage of wood waste received and landfilled or recovered at landfills in 1995, 1998, and 2016. Recovered wood waste as a percentage of total wood waste received at MSW landfills.

	1995	1998	2016
Total Wood Waste Received (Tonnage)	38,540,000	29,772,000	30,199,000
Wood Waste Landfilled (Tonnage)	28,220,000	20,840,000	20,006,000
Wood Waste Recovered (Tonnage)	10,320,000	8,932,000	10,193,000
Recovered Wood Waste as a % of Total Wood Waste Received	26.78%	30.0%	33.8%

Wood Recovered by Category

MSW facilities were asked to group the tonnage of wood waste recovered into one of five categories: pallets, crates, construction related wood, woody yard waste, and an "other" category for any wood not included in the any of the other four categories. Woody yard waste made up the largest portion of wood recovered by MSW facilities with each facility recovering a mean of 6,444 tons

Table 32). This woody yard waste was most likely ground into mulch for sale or pickup by local residents and businesses. The South, with each facility recovering a mean of 13,678 tons, and the West with a mean of 3,173 tons per facility, recovered much higher mean tonnages than the Midwest and Northeast where 960 tons and 639 tons of woody yard waste were recovered per facility, respectively. The frequency and radius of curbside pick-up programs and how the waste is processed may vary by region, but it would be expected that recovery for this category would return a high value because woody yard waste usually does not contain metal or other harmful contaminants, making it easy to chip and grind.

Approximately 486 tons of construction related wood waste was recovered per facility in 2016. This was much less than the amount of construction related wood waste landfilled, previously shown to be 8,225 tons. The intermingled nature of construction debris makes it difficult to recover. Specialized equipment and labor are often required to do so successfully, especially for materials like wood that have lower value than easily extractable materials like metal (Goldstein, 2006).

Table 32 Mean tonnage of wood waste recovered by category per facility that had wood recovery operations in 2016.

Mean Amount of Recovered Wood per MSW Facility by Category (Tonnage)					
Recovery Category	**All Regions**	**Midwest**	**South**	**Northeast**	**West**
Pallets	325	395	360	48	270
Crates	237	113	160	78	488
Construction Related Wood	486	19	402	288	1,073
Woody Yard Waste	6,444	960	13,678	639	3,173
Other	97	0	141	38	143

MSW facilities that indicated that they recovered pallets reported a mean of 325 tons of pallets per facility in 2016. Regionally, facilities in the Midwest recovered the most, with a mean of 395 tons of pallets per facility, while the Northeast had the lowest, with a mean of 48 tons per facility (Table 33). Despite the differences between regions in this category, the Steel-Dwass non-parametric multiple comparison test found no significant differences exist at confidence level of 95% (Appendix A).

Table 33 Mean tonnage of pallets recovered per MSW facility in 1995, 1998, and 2016 by region

Mean Amount of Pallets Recovered per MSW Facility by Region (Tonnage)			
Region	**1995**	**1998**	**2016**
All Regions	1269	1158	325
Midwest	810	1535	395

South	1357	949	360
Northeast	961	1354	48
West	1322	663	270

When the mean tonnage of pallets recovered per facility is compared historically, a 74.4% decrease was observed between 1995 and 2016, and a 71.9% decrease was observed between 1998 and 2016. Since 1998, the mean tonnage of pallets recovered per facility decreased in every region. This was especially prevalent in the Northeast, which experienced a 96.4% decrease in the mean tonnage of pallets recovered per facility from 1998 to 2016.

Nationally, just under 15.9 million pallets were recovered in 2016 (Table 34). The South and the West recovered the most with 6.1 million and 5.2 million pallets, respectively. The Midwest recovered 786,908 pallets and the Northeast recovered just 251,792 pallets. Every region, except the West, experienced a large decrease in the number of pallets recovered since 1998. When compared to previous studies, the 2016 estimate of 15.9 million pallets recovered represents a 50.3% decrease from the 32 million pallets recovered in 1995 and 27.6% decrease from the 22.1 million pallets recovered in 1998 (Table 34). The Midwest saw an 88.9% decrease in the number of pallets landfilled from 1998 to 2016 despite being the only region with an increase in the number of pallets recovered from 1995 to 1998.

Table 34 Total number of pallets recovered by region at MSW facilities in 1995, 1998, and 2016

Total Number of Pallets Recovered by Region			
	1995	**1998**	**2016**
All Regions	32,030,000	22,052,000	15,887,000
Midwest	2,460,000	7,146,000	786,908
South	19,400,000	8,218,000	6,116,000
Northeast	4,500,000	3,794,000	251,792
West	5,670,000	2,894,000	5,221,000

Although both the numbers of pallets landfilled and those recovered have decreased since 1998, the number of pallets recovered is greater than the number of pallets landfilled for the first time since these studies began (Table 35). When the number of pallets landfilled and recovered at MSW facilities are combined, the total has decreased from 184.8 million in 1995 to 160.4 million in 1998, down to 29.0 million in 2016 (Table 35). The percentage of total pallets arriving at MSW facilities that are recovered as opposed to landfilled has risen from 13.8% in 1998 to 54.8% in 2016. The is a positive finding for the state of wood and pallet recovery; it means that pallet users are sending fewer pallets to landfills, and landfills are doing a better job of recovering them than in previous years.

Table 35 Total number of pallets received, landfilled, and recovered at MSW landfills in 1995, 1998, and 2016. Percent of total pallets received from recovered pallets.

	1995	1998	2016
Total Number of Pallets Received	184,775,000	160,412,000	28,982,081
Number of Pallets Landfilled	152,745,000	138,360,000	13,094,815
Number of Pallets Recovered	32,030,000	22,052,000	15,887,265
Percent Recovery of Total Pallets Received	17.3%	13.8%	54.8%

Wood Chip Sales

Facilities were asked to indicate the total tonnage and average price per ton for wood chips sold. While the previous surveys had asked for the specific uses chipped pallets were sold for, this questionnaire only asked for wood chips to be split into three use categories to improve the ease of response. These categories included wood chips sold for (1) residential use, (2) commercial use, and (3) "other" use. After receiving the results, the responses for all three categories were combined into one value due to the low number of respondents in each region. When all of the values were combined, the average ton of wood chips sold for $14.81, and the facilities that sold wood chips sold an average of 1,660 tons per facility.

Respondents were given space to provide additional information while describing their wood chip sales. Many respondents indicated that they do not charge local residents for wood chips or mulch. Sometimes hardwood chips are separated for sale to the public while softwood and pallet chips are used within the landfill operation. It is common to utilize wood chips for fuel, facility operations, as a material for daily cover, in road construction, or as an addition to composting mix. Several facilities indicated that is possible to mix this ground wood waste with commercial food waste and then sell the compost.

Pallet Separation

Participants were asked if they separated pallets from other types of wood waste diverted to their recovery areas in 2016. If they did, they were provided three options to indicate why the pallets were being separated: (1) separated for repair/recycling, (2) separated to be sold to a pallet recycler, and (3) separated for other uses. If they selected other uses, a short response area was provided where they could further elaborate on why the pallets were being separated. Overall, 27.8% of wood recovery facilities indicated that they separated pallets from other wood waste. Of these, 92% of facilities that separated pallets for recovery did so for other uses. Only 4% did separated them for repair and another 4% did so to sell them to pallet recyclers (Table 36).

When asked to describe these other uses, respondents indicated several different answers. The most common reasons found for why the landfills separate pallets from other waste was either to give them away to local residents or to process them into wood chips. Respondents indicated a variety of uses for wood chips including being used for boiler fuel, composting, cover material, or as a wet weather road cover and turn around base. Several respondents indicated that when good quality pallets were received at their facilities, they are used to ship out universal waste such as E-waste and batteries. This is a benefit that discarded pallets can bring to landfills because it saves them the cost associated with purchasing new pallets. It also extends the useful life of the wood used to construct the pallets by keeping it out of the landfill longer.

Table 36 Percent of facilities separating pallets by intended use.

Percent of Facilities Separating Pallets	
For Repair	1.10%
For Other Uses	25.58%
For Pallet Recycler	1.10%

Alternative Daily Cover

Wood waste can be ground and used in conjunction with other earthy materials as a way to meet landfills' regulatory requirements of alternative daily cover (ADC) to controls odor, vectors, fires, litter, and scavenging (Fantell and Flannagan, 2011). Approximately 22% of facilities indicated that they use recovered wood waste for ADC. Facilities that use recovered wood waste for ADC utilized a mean of 7,753 tons per facility in 2016 (Table 37). Facilities in the South utilized more recovered wood waste for ADC than any other region. This suggests that it is an important part of their facility operations. Facilities in the Northeast used the lowest amount of ADC at their recovery areas with a mean of 1,046 tons per facility while facilities in the West utilized a mean 1,967 tons and facilities in the Midwest used 2,295 tons of recovered wood waste for ADC in 2016.

Table 37 Mean tonnage of alternative daily cover (ADC) for facilities that used recovered wood waste for this purpose by region.

Region	Mean Amount of Recovered Wood for ADC per facility (Tonnage)
All Regions	7,753
West	1,967
Midwest	2,295
Northeast	1,046
South	14,927

Pallets Sold at MSW Landfills

Facilities surveyed in this study were asked how many pallets they sold in 2016 and for what price. There was only one response to this question, and it indicated that the selling price was $4.60 when a pallet was sold to a pallet recycler. This is higher than the present-day value of $2.30 that the previous study found as the price for an individual pallet sold for reuse (using the CPI inflation method on the responses from January 1998).

Change in Volume of Pallets Received over the Past Two Years

When asked how the volume of pallets received at their recovery facilities has changed over the past two years, 4% of respondents indicated that they have experienced an increase while 12% saw a decrease, 76% experienced no change at all, and 8% reported that their recovery facilities have been in operation for less than two years (Table 38). The 4% of facilities that reported an increase in the volume of pallets over the past two years indicated a 2% mean increase. This is a large change from the 1998 study. In that study, the 27.2% of the facilities reporting an increase indicated a 21% mean increase. In 2016, the 12% of facilities that indicated a decrease reported a mean of 39% while in 1998, 9% of facilities indicated a mean decrease of 30%. The percentage of facilities indicating no change increased from 59.2% in 1998 to 76% in 2016.

The percentage of facilities experiencing a decrease in volume and mean percent change were similar in 1998 and 2016. However, there was a large decrease in the percent of facilities indicating an increase of pallet volume received at their recovery areas and a decrease in their mean percent increase. And, there was an increase in the percentage of facilities indicating no change. All of this suggests that the overall number of pallets going to recovery areas is stabilizing or decreasing year to year.

Table 38 Percent of MSW wood waste recovery facilities reporting a change in the volume of pallets received in 1998 and 2016 with the mean change in volume of pallets received.

	1998		2016	
Response Category	**Percentage of Facilities**	**Mean Percent Change**	**Percentage of Facilities**	**Mean Percent Change**
Increased	27.00%	21.00%	4.00%	2.00%
Decreased	9.00%	-30.00%	12.0%	-39.00%
No Change	59.20%		76.00%	
Not in Operation Over Two Years	3.80%		8.00%	

Waste to Energy Conversion

Participants in the survey were asked if they converted waste that would otherwise be landfilled into energy through combustion or incineration, just 14.63% of all facilities report operating a waste to energy conversion facility, through which they redirect an average of 24,000 tons of waste from the landfill. Respondents reported that over 53% of this converted waste is made of wood.

3.4 Conclusions

1. The total estimate for waste generated nationally per this study was 249 million tons which was an increase from the 1998 estimate of 239 million tons but a decrease from the 1995 estimate of 293 million tons.
2. Regionally, the South receives the most waste per facility and has the most number of facilities. It also handles 68.8% of all wood recovered nationally (6,888,638 tons) and 75.3% of all wood landfilled nationally (15,070,472 tons) by MSW landfills, which is more than all of the other regions combined.
3. The amount of wood waste received at MSW landfills has increased by 1.43% since 1998. However, the amount of wood waste landfilled decreased by 4% while the amount of wood waste recovered increased by

14.1%. This has resulted in the proportion of total wood waste received and then recovered increasing from 30.0% in 1998 to 33.8% in 2016

4. Twenty-nine million pallets were received at MSW landfills in 2016. Of these, 13.1 million were landfilled and 15.9 million were recovered. This represents a 90.5% decrease in the number of pallets landfilled and a 28% decrease in the number recovered compared to the 1998 study. The proportion of pallets received that were recovered has increased from 13.8% in 1998 to 54.8% in 2016. The decrease in the number of pallets landfilled is much larger than the number of pallets recovered at MSW facilities since 1998. These findings indicate that, overall, fewer pallets are going to landfills, and the ones that arrive are more likely to be recovered. This may have been caused by increased awareness of supply chain spending brought about by challenging economic conditions since the previous studies. Because of the value derived from used pallets, more be being captured by recovery operations before arriving at landfills.
5. Most facilities indicated that the volume of pallets received at recovery areas has not changed or has decreased in the past two years. When combined with the findings that the number of recovered pallets has decreased by 28% since 1998, this indicates that fewer pallets are going to recovery areas. With few facilities reporting an increase in the number of pallets received at recovery areas and 5.1% reporting that they added wood recovery areas in the past two years, we can extrapolate that most facilities that foresaw the benefits and had the ability to add a wood recovery area have done so since 1998.
6. There were 508 million new pallets, as well as 341 million repaired or refurbished pallets, produced by pallet manufacturers and recyclers in 2016 in the United States (Gerber 2016). The results of this study indicate that 5.7% of all new pallets produced was transported to MSW landfills in 2016 but only 2.6% of all pallets produced were landfilled and 3.1% were recovered into other value adding products.

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4. An Investigation of Wood Pallets Landfilled and Recovered at US Construction and Demolition (C&D) Facilities

Zachary Shiner, Laszlo Horvath, Philip Araman

Construction and Demolition (C&D) landfill facilities throughout the United States were surveyed to gain a better understanding of the characteristics of their waste stream. The survey was administered through a mailed questionnaire that included an option to complete it online. This survey was modeled after similar studies conducted by Virginia Tech in 1995 and 1998. It is estimated that 77.8 million tons of C&D waste was received at landfills in the United States in 2016, representing nearly a 93% increase from the 40.3 million tons landfilled in 1998. Overall, the tonnage of total wood waste received at C&D landfills increased from 19.8 million tons in 1998 to 29.7 million in 2016. However, it was also found that 80% of the wood waste received was recovered in 2016 compared to only 18% in 1998. The total number of pallets received by C&D landfills went down by 34% from 56.4 million in 1998 to 37.1 million in 2016. Out of all pallets received by C&D facilities in 2016, 67% were recovered. This was a large increase from the 28.2% recovered in 1998.

Keyword: Municipal Solid Waste (MSW), Wood Pallets, Wood Waste

Author Contact: Department of Sustainable Biomaterials, Virginia Tech, 1650 Research Center Dr., Blacksburg, VA 24061, USA; *Corresponding author: lhorvat@vt.edu

4.1 Introduction

Construction and Demolition (C&D) waste includes waste generated during the construction and demolition of residential and commercial structures as well as public works projects like roads and bridges. This waste is typically considered inert, meaning that it poses little threat of hazardous interaction with the surrounding air and groundwater. Because of this, U.S. regulations do not require impermeable liners or a leachate removal system; however, some hazardous materials may still be present within these landfills (Powell *et al.*, 2015).

Research conducted on the C&D waste stream in the United States has been sparse, and the estimates vary significantly. In 2014, The U.S. Environmental Protection Agency (EPA) estimated that 534 million tons of C&D waste was generated compared to only 258 million tons of MSW (United States Environmental Protection Agency, 2016). In 2010, Falk and Mckeever of the U.S. Forest Service estimated that just 130 million tons of MSW was generated in the United States (Falk and McKeever, 2012). An older 2002 study conducted by Townsend and Cochran estimated that somewhere between 672 and 859 million tons of C&D waste were generated in the United States (Cochran and Townsend, 2010). However, a large portion of the C&D waste stream is recovered, and it was estimated by the Construction Demolition and Recycling Association that 70% of all C&D waste is recovered and put to beneficial use by C&D recyclers. Therefore, only 30% of all C&D waste ends up landfilled (CDRA, 2014).

The construction and demolition of buildings results in many different types of waste, and wood is one of the most prominent. This wood is typically composed of forming and framing lumber, stumps, plywood, laminates, scraps, and pallets used to transport materials to the construction site (Turley *et al.*, 2000) Several studies have attempted to quantify the proportions of all C&D waste that is comprised of wood., These estimates vary greatly from study to study. However, it would seem that wood makes up a smaller portion of the waste stream year after year. In 2014, the EPA found that wood waste made up the third largest portion, or 7%, of all C&D waste generated (United States Environmental Protection Agency, 2016). In 2010, Falk and McKeever estimated that 28% of all C&D waste was generated from wood. In 1998 and 1995, Virginia Tech conducted studies focusing on wood and wood pallet disposal and recovery at C&D facilities. These studies found that 38% and 40%, respectively, of all of the waste received at each facility was wood (Corr *et al.*, 2000).

Pallets, specifically, make up a sizable portion of the C&D waste stream, and they are of special interest to several organizations because of the potential for reuse and recovery. Virginia Tech conducted two of the most in-depth studies on C&D pallet waste in 1995 and 1998. These studies found that approximately 32.7 million and 40.5 million pallets were landfilled at C&D facilities, making up 2.12% and 3.29% of the total waste received at C&D landfills in 1995 and 1998, respectively (Corr *et al.*, 2000). Additionally, the same studies found that 5.9 million and 15.9 million pallets were recovered at C&D facilities in 1995 and 1998, respectively.

4.2 Experimental

The questionnaire featured 18 questions intended to collect information about the waste stream characteristics of construction and demolition (C&D) landfills. The main types of questions asked were numerical response open-ended questions, closed-ended multiple selection questions, and partially close-ended questions containing an "other" option.

The main method of data collection was a mailed survey with the option for it to be completed online because this had the ability to reach a dispersed sample population at a low cost while allowing time for the respondents to gather the necessary data to fill out the survey (Don A. Dillman, 2009). The questionnaire and its content was intended to be comparable to similar studies completed in 1995 and 1998 by Virginia Tech. There were questions regarding facility characteristics, waste received and landfilled, and tipping fees, then it moved on to questions regarding the landfilling and recovery of wood waste and specifically wood pallets.

The C&D facility selection was based on the classifications of landfill types found through information publically available on the internet or through records requests. Due to the variety of different landfill types, it was important to identify the appropriate target population. Facilities were chosen if they aligned with the characteristics of a C&D landfill as defined by the United States Environmental Protection Agency (USEPA). Hawaii and Alaska were not included in this study for several reasons, but mainly because they had not been included in the previous studies (Bush, Araman and Corr, 2001). Before removing any facilities that indicated they did not receive C&D waste, the population consisted of 1,039 facilities.

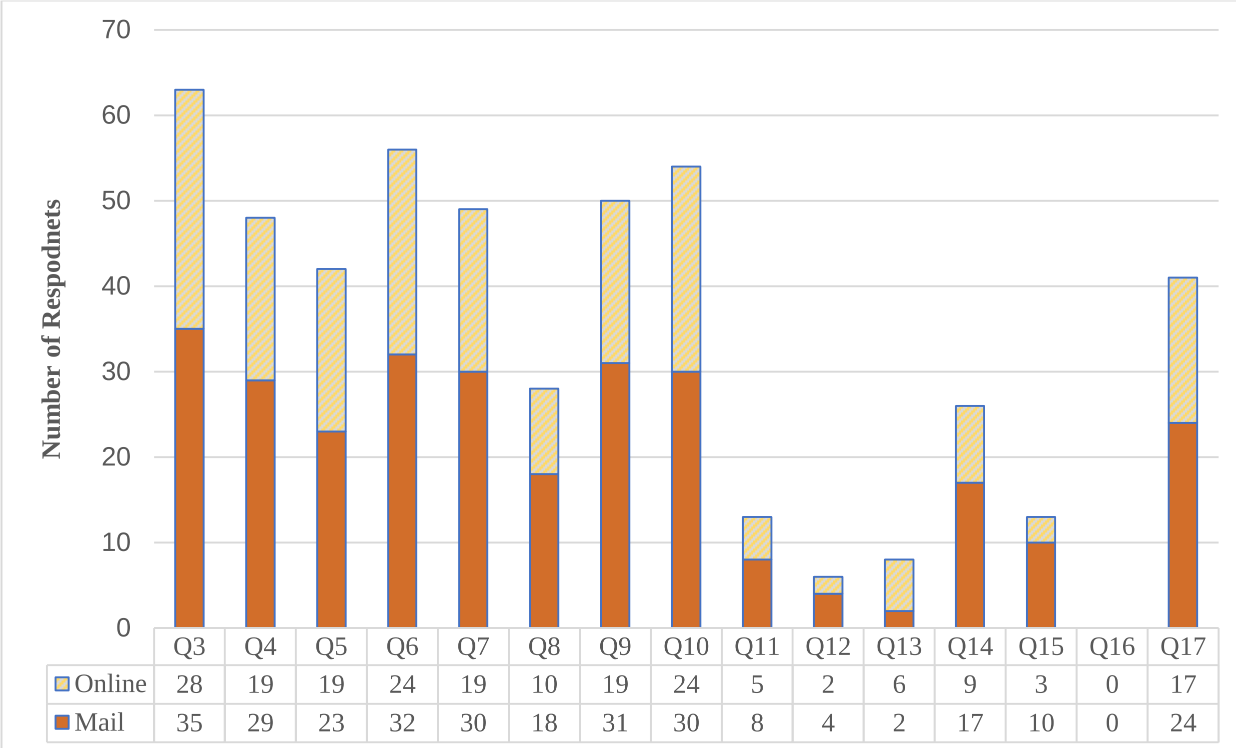
In June of 2017, questionnaires were sent out through the United States postal service to a list of facilities with a cover letter as well as a prepaid and addressed return envelope. Each questionnaire had a unique identifier that could be used to access and complete the online version of the survey through Qualtrics online data collection software (Provo, Utah). A temporary website was created at the URL, www.vtlandfillsurvey.org, to provide an easily accessible link to the online survey. Within 10 business days of the initial mailing, a 3”x 5” postcard was sent out to remind the facilities to complete the survey. Ten days following the postcard, a second copy of the questionnaire was sent out to any facility who had not yet turned in a response to the first mailing. If email addresses were found for any of the non-responding facilities after mailing the second copy of the questionnaire, two reminder emails were sent out using MailChimp (Atlanta, GA, USA) email distribution software.

Facilities were grouped into four geographical regions according to the guidelines of the U.S. Census Bureau to allow for comparison to the studies of previous years. Several steps had to be taken to apply facility estimates to the total national population. The mean facility tonnage was based only on facilities that responded to question number three. To calculate the total amount of waste received at C&D landfills nationally, the mean tonnage of waste received per facility was multiplied by the number of facilities in each region and then summed together. There were not enough respondents to have a regional comparison for any question beyond total waste received. To determine wood landfilled and recovered by category, the same methodology was followed. The sums of each individual category were added together, and the percentage of the total wood landfilled or recovered was determined by dividing the total sum of all wood landfilled or recovered by the sum of the category. This percentage was then applied to the total waste received nationally.

Table 39 U.S. Census Bureau regional groupings of states.

West	Midwest	South	Northeast
Arizona	Illinois	Alabama	Maine
California	Indiana	Arkansas	Vermont
Colorado	Iowa	Georgia	New Hampshire
Idaho	Kansas	Kentucky	Pennsylvania
Montana	Michigan	Louisiana	Massachusetts
Nevada	Minnesota	Mississippi	New Jersey
Oregon	Missouri	North Carolina	Connecticut
Utah	Nebraska	South Carolina	Rhode Island
Washington	North Dakota	Tennessee	New York
Wyoming	Ohio	Virginia	Delaware
New Mexico	South Dakota	West Virginia	
	Wisconsin	Maryland	
		Florida	
		Oklahoma	
		Texas	

Out of 1,039 Construction and Demolition facilities surveyed, 63 responses were received for a 6.1% response rate. The first two questions of the survey asked respondents to indicate if they operated a C&D landfill and what state they were located in. If only these two questions were answered, it provided little additional value to the study, thus the breakdown of responses provided in Figure 12 begins with question 3.



	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
Online	28	19	19	24	19	10	19	24	5	2	6	9	3	0	17
Mail	35	29	23	32	30	18	31	30	8	4	2	17	10	0	24

Figure 12 C&D responses by question and response type

The distribution of responses was left tail skewed, indicating that there were a high number of smaller facilities and relatively few larger ones that responded. As shown in table 40, the mean tonnage of waste received per facility was 74,911 tons while the median was 22,081 tons. This is a basic way to indicate that the distribution was right tailed skewed, indicating more facilities receive lower amount of waste than those that receive large amounts.

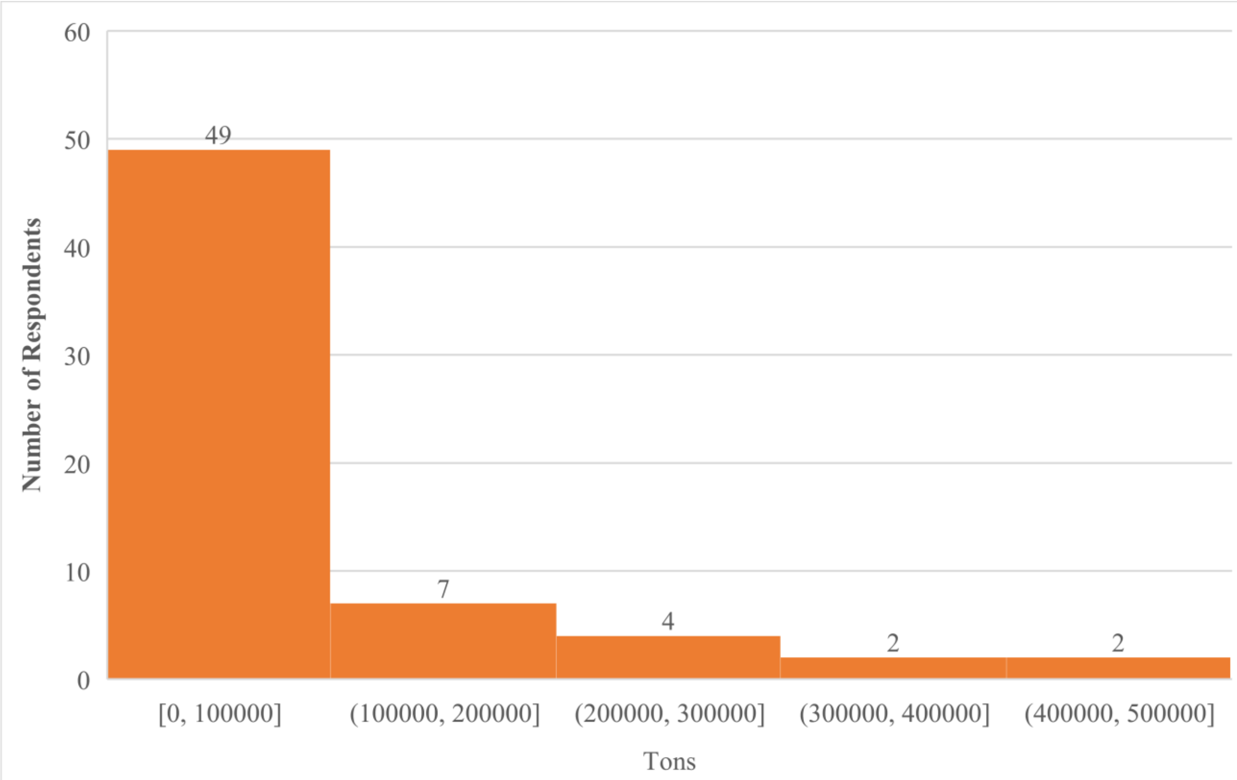


Figure 13 Distribution of responding C&D facilities by tonnage of waste received.

4.3 Results and Discussion

C&D Waste Received per Facility

In 2016, each Construction and Demolition (C&D) landfill facility in the United States received a mean of 74,911 tons of total waste per facility (Table 40). Facilities in the South received the highest mean tonnage at 109,514 tons each, while facilities in the Midwest received the lowest mean at 26,016 tons. Using the Steel-Dwass nonparametric multiple comparison at a 95% confidence level, there were no significant differences in the distributions of waste received in each of the regions for tons of waste received (Appendix A).

Table 40 Mean amount of waste received per C&D facility by region in 1995, 1998 (Corr 2000), and 2016

	Mean Amount of C&D Waste per Facility (Tons)		
	1995	**1998**	**2016**
All Regions	29,307	36,226	74,911
West	28,828	67,207	49,768
Midwest	25,715	32,840	26,016
Northeast	13,687	55,549	69,576
South	36,540	29,871	109,514

C&D facilities in the South received 57% more waste than those in the Northeast, which had the second highest amount at 69,576 tons per facility. The South also experienced the greatest increase in waste received when compared to the previous surveys; it had over a 266% increase from 1998 to 2016. Facilities in the West and the Midwest saw 29.9% and 20.8% decreases in the amount of waste received, respectively, when compared to the 1998 study. The Northeast is the only region that has seen consistent growth in the tonnage of waste received since 1995 (Table 40).

Historically, this represents over a 106% increase in the mean tonnage of waste received at each C&D landfill facility when compared to the 1998 Virginia Tech survey. One possible explanation for this is that the number of C&D landfills has decreased or that the amount of waste being sent to landfills has increased. Previous research indicates that the number of C&D landfills decreased from 1,436 in 1995, to 1,095 in 1998, to 1,039 in 2016 (Bush, Araman and Corr, 2001). Additionally, estimates provided by the United States Environmental Protection Agency (US EPA) indicates that the total C&D waste generated has soared from 170 million tons in 1998 to their most recent estimate of 534 million tons in 2014 (United States Environmental Protection Agency, 2016).

Total C&D Waste Received

To calculate the total amount of waste received at C&D landfills nationally, the mean tonnage of waste received at each facility was multiplied by the number of facilities in each region and then the totals of the four regions were summed together. It was found that the amount of total waste received at all C&D landfills nearly doubled from 40.3 million tons 1998 to 76.8 million tons in 2016 (Table 41). Every region experienced an increase in the amount of C&D waste received since 1998. The Midwest was the only region that experienced less than a 90% increase when compared to the previous study. When compared to the 1995 results, it seems that the mean tonnage of waste within each region increases year to year.

Table 41 Total amount of C&D waste generated by region in 1995, 1998, and 2016

	Total National C&D Waste (Tons)		
	1995	**1998**	**2016**
All Regions	42,169,000	40,341,000	77,834,000
West	3,132,000	7,796,000	22,681,000
Midwest	10,843,000	12,282,000	12,768,000
Northeast	2,939,000	4,611,000	12,195,000
South	25,255,000	15,652,000	30,189,000

The Virginia Tech estimates all end up being significantly lower amount than the EPA studies of similar time periods. The EPA estimated 136 million tons of C&D waste in 1996, increasing to 170 million tons in 2003, and increasing again to 534 million tons in 2014 (which is more than twice the amount of municipal solid waste generated in the same year) (US EPA, 2017c). It is important to note that the EPA estimates include all generated waste while the Virginia Tech studies only account for waste that is received at landfills. If the survey population had included material recovery facilities (MRFs), or facilities that sort and recycle waste without landfilling, it would be expected that the total amount of waste would be higher, and the estimates for recovered waste would be greater as well.

C&D landfills receive a variety of materials besides wood, including: various types of metal pipes and fixtures, concrete, masonry, asphalt aggregate, bricks, gypsum drywall, plastics, and some chemical or hazardous waste like asbestos and paint (Letcher and Vallero, 2011). Some of this waste is easy to recycle, while other types are more difficult and require specialized processing offsite. A large portion of waste in the C&D waste stream is recovered, and it was estimated by the Construction Demolition and Recycling Association that 70% of all C&D waste is recovered and put to beneficial use by C&D recyclers; therefore, only 30% of all C&D waste ends up in landfills (CDRA, 2014).

A portion of C&D waste also goes directly from the source to recovery. For example, we spoke to one landfill manager who mentioned that the materials from demolished stadium bleachers had been transported directly to a parking lot where their county fair was going to be held. This landfill was able to count the tonnage of that waste as recovered, even though the facility never actually received it.

Waste Breakdown by Type

Participants were asked to estimate the breakdown of the C&D waste received at their facilities into one of four categories. These include: landfilled normal waste, landfilled wood and brush, recovered normal waste, and recovered wood and brush. It was found that 63% of all waste received at C&D facilities is landfilled, while the remaining 36% is recovered (Figure 14). At facility level, wood and brush make up 38% of all waste received, which is comparable to the findings of Falk and McKeever of the US Forest Service in 2012, who found that 28% of C&D waste generated is from wood (Falk and McKeever, 2012).

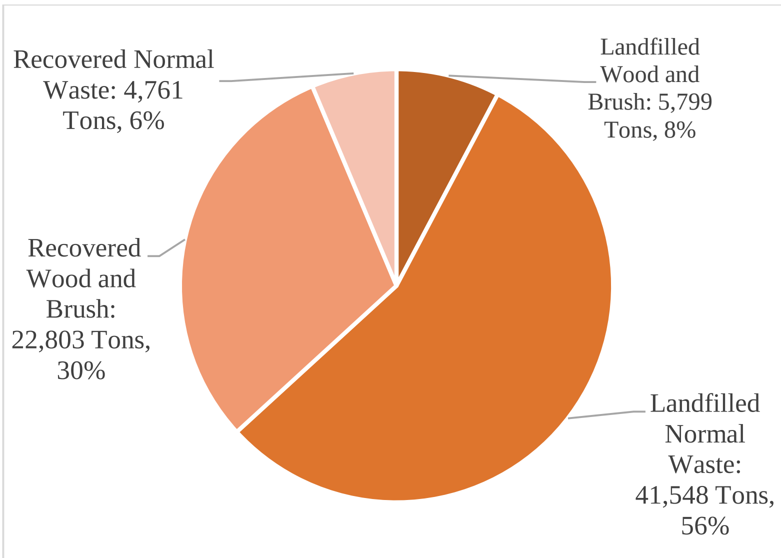


Figure 14 Waste received at US C&D landfilled by category. Tonnage and percent of mean waste received per facility.

Landfilled normal waste makes up the largest portion of all waste received with each C&D facility. They landfill a mean of 41,548 tons per facility, or 56%, of waste received (Figure 14). This is expected because the study only surveyed C&D facilities that were licensed to landfill waste. Many C&D facilities are materials recovery facilities (MRFs) which only sort, recover, and divert waste to the appropriate locations. They can then sell the recovered waste to interested customers. These facilities may be receiving then directly recycling large portions of their waste stream. For example, the Monterey Regional Solid Waste Authority has a MRF in their district that diverts 65% of C&D waste from the landfill (Monterey Regional Waste Management Authority, 2017).

The mean for normal waste recovered per C&D landfill in 2016 was 4,761 tons per facility, which was 6% of the total waste received. It is interesting that there were 22,803 tons of wood and brush recovered per facility. This means that it is the most commonly recovered material at C&D landfills. This could be because it is relatively easy to process as long as it does not contain metal or other contaminants. Nationally, there was more landfilled normal waste than any other category (Table 42). This is expected because the type of facility that was surveyed in this study primarily accepts normal waste in the form of construction and demolition materials and debris. The results also indicate that approximately 38% of all waste received was wood and that nearly 80% of the wood received was recovered.

Table 42 Tonnage of waste received at US C&D landfills by category.

Waste Category	Total National Waste Received at Landfills (Tons)
Landfilled Wood and Brush	6,025,000
Landfilled Normal Waste	43,168,000
Recovered Wood and Brush	23,693,000
Recovered Normal Waste	4,947,000

Wood and Brush Landfilled

There were 5,799 tons of wood and brush landfilled per facility in 2016. This represents an 84.85% decrease from the 1995 value of 38,265 tons and a 48.7% decrease from the 1998 mean of 11,300 tons (Table 43).

Table 43 Mean tonnage of wood and brush landfilled per C&D facility

	1995	1998	2016
Mean Wood and Brush Landfilled per Facility (Tonnage)	38,265	11,300	5,799

Wood and brush landfilled represents 8% of all waste received at C&D landfills in 2016. This is a large decrease from the previous studies of 38.2% in 1995 and 40.3% in 1998 (Table 44). However, the results also indicate that the mean tonnage of wood and brush recovered by C&D facility has increased.

Table 44 Wood and brush as a percent of total waste received at C&D landfills in 1995, 1998, and 2016

	1995	1998	2016
Total National C&D Waste (Tonnage)	42,169,000	40,341,000	77,834,000
Percent of Facilities Landfilled Wood and Brush	38.2%	40.3%	8%
Total National Wood and Brush Landfilled (Tonnage)	16,108,558	16,257,423	6,025,000

When these percentages are taken with the total tonnage of C&D waste landfilled each year, the total tonnage of wood and brush landfilled were nearly the same for 1995 and 1998 with 16,108,558 tons and 16,257,423 tons, respectively (Table 44). In 2016, the amount of wood and brush landfilled was only 6,025,207 tons, a 62.9% decrease from 1998.

The total amount of wood and brush recovered at C&D landfills in 2016 was 23,692,873 tons. This is a large increase compared to the 1998 value of 3,560,00 tons and the 1995 value of 617,000 tons (Table 45). When the amount of landfilled and recovered wood and brush was combined, the total amount of wood and brush that arrived at C&D facilities was 29,718,080 tons. This is 78% increase compared to 1995 and a 50% increase compared to 1998.

Table 45 Total tonnage of wood and brush received at C&D landfills. Total tonnage of wood and brush recovered and landfilled. Proportion of wood and brush recovered of total wood and brush for 1995, 1998, and 2016.

	1995	**1998**	**2016**
Total National Wood and Brush Received at C&D Landfills (Tonnage)	16,726,000	19,817,000	29,718,000
Total National Wood and Brush Recovered (Tonnage)	617,000	3,560,000	23,693,000
Total National Wood and Brush Landfilled (Tonnage)	16,109,000	16,257,000	6,025,000
Percent of Total National Wood and Brush Recovered	3.7%	18.0%	79.7%

The results indicate that the amount of wood and brush landfilled decreased by 62.9% from 16.3 million tons in 1998 to 6.0 million in 2016, and the amount of wood and brush recovered has increased by 565% since 1998. This is an interesting finding because while the overall tonnage of wood and brush arriving at C&D landfills has increased from 1998 to 2016, the proportion of wood and brush that is recovered has also increased from 18.0% to 79.7%. This means that C&D facilities are effectively promoting waste haulers to separate wood and brush entering their landfills, and they are able to recover it more effectively than in the past. It could also suggest that facilities have more capital investment in the necessary equipment than facilities that were surveyed in 1998.

Tipping Fees

Facilities were asked to provide information regarding the tipping fees that they charge for different types of waste. The mean tipping fee for unsorted waste at all C&D facilities was $42.88 per ton. The mean tipping fee for presorted waste was $37.70 per ton (Figure 15). Presorted waste is easier to process and takes up less volume than unsorted waste. It is also common for C&D facilities to charge by cubic yard because that encourages haulers to compact the waste themselves before bringing it to the scale house.

The mean tipping fee for sorted wood and brush was $28.79 per ton and for recovered pallets it was $29.80 per ton (Figure 15). Tipping fees for pallets are higher because some facilities consider pallets normal waste and do not offer a discount for them as is often done for wood and brush. Pallets contain metal fasteners and are harder to process than wood and brush. There were no comparative historical values for the tipping fees of these two types of waste.

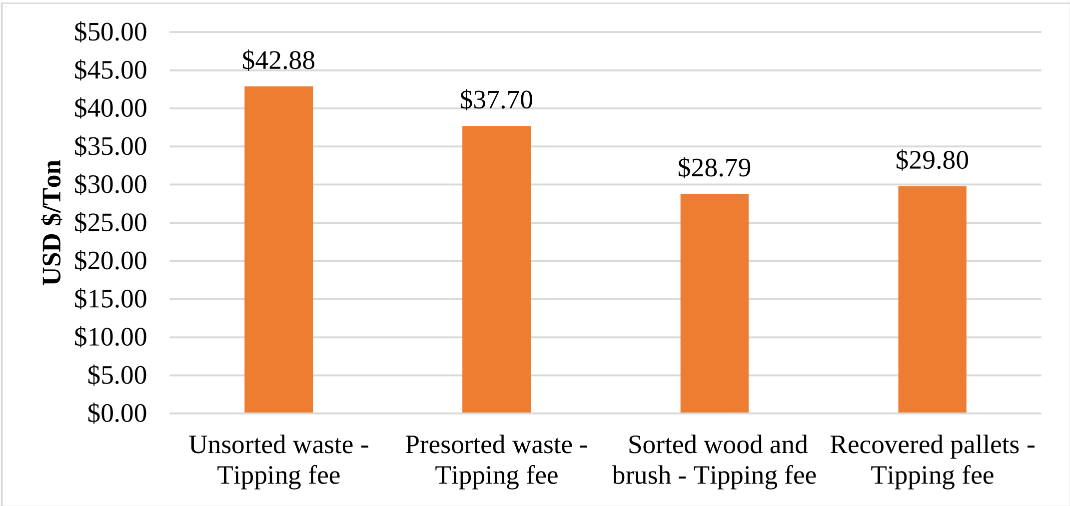


Figure 15 Mean tipping fees among C&D facilities by waste type in 2016

When the mean tipping fees of the previous surveys are adjusted to present day value using the Consumer Price Index (CPI), the cost of landfilling unsorted C&D waste has increased slightly from $39.71 per ton in 1995 to $42.88 in 2016 despite decreasing significantly from 1995 to 1998 (Figure 16).

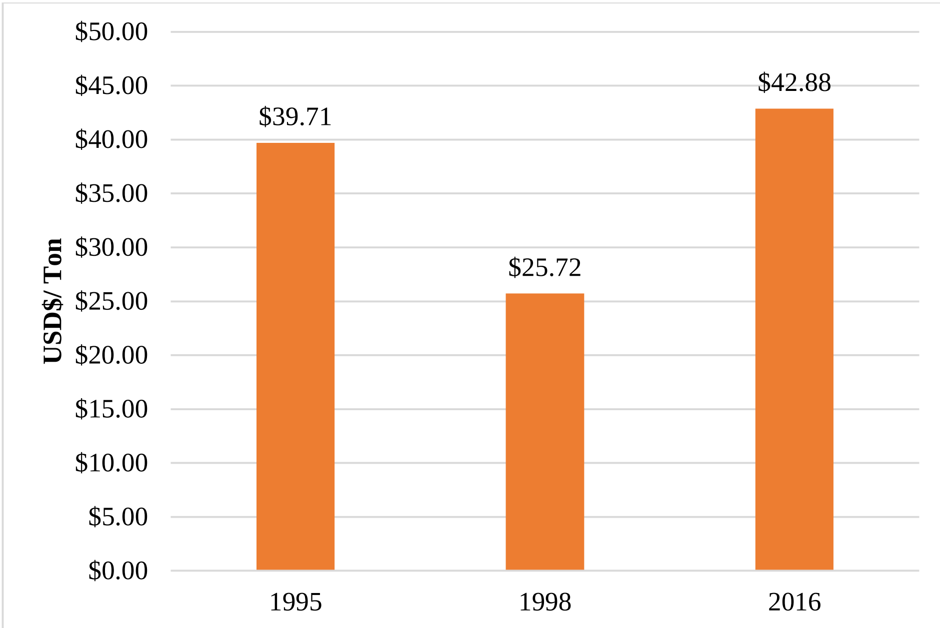


Figure 16 Tipping fees at US C&D landfills in 1995, 1998, and 2016 for unsorted C&D waste per ton. Original prices were adjusted using CPI from January of the year of the study.

The present-day value of the historical tipping fees for sorted waste at C&D landfills follows a similar trend to the year to year changes for unsorted waste, decreasing from 1995 to 1998 and then increasing in 2016 (Figure 17). This could be due to several factors such as available landfill space, regulations, or the large increase in the amount of C&D waste generated between these two time periods as noted by the EPA (United States Environmental Protection Agency, 2016).

Figure 17 Tipping fees at US C&D landfills in 1995, 1998, and 2016 for sorted C&D waste per ton. Original prices were adjusted using CPI from January of the year of the study.

Wood Landfilled per Facility

When respondents were asked to break down wood waste landfilled by category, industrial C&D wood waste had the highest tonnage at 2,586 tons (Figure 18). While the amount of industrial C&D waste decreased from 1998, when each facility landfilled 3,304 tons, the percent of total waste that is industrial C&D waste is gone up from 29.3% in 1998 to 44.8% in 2016 (Table 46). Research provided by the EPA also supports a high percentage of industrial waste; it was found that 61% of all C&D waste comes from non-residential activities in 2014 (US EPA, 2017c).

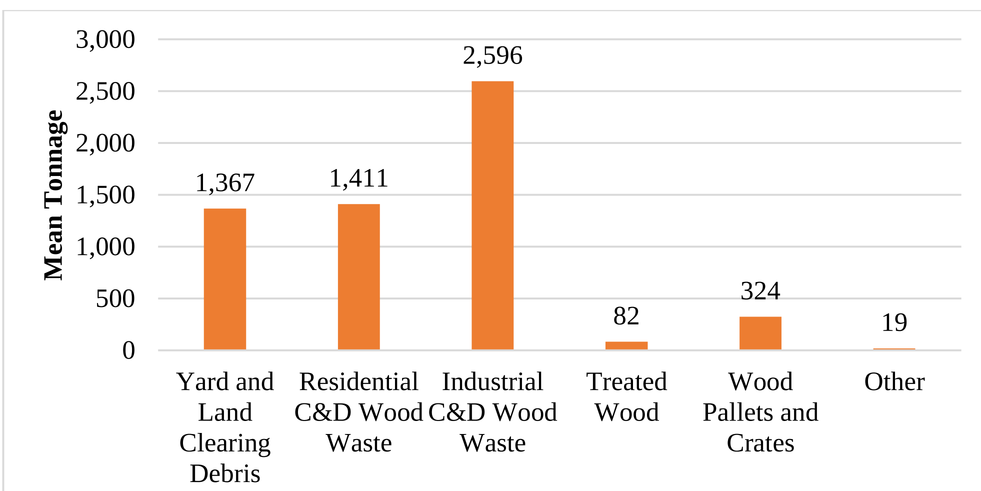


Figure 18 Mean tonnage of wood waste landfilled by category per US C&D facility in 2016

The mean tonnage of residential wood waste landfilled per C&D facility was 1,411 tons in 2016 (Figure 18). This made up 24.3% of all wood waste landfilled at C&D facilities in 2016, which is a reduction from 32.9% in 1998 (Table 46). The actual amount decreased from 2,461 tons in 1998, representing a 42.7% reduction. Housing starts seem to have little correlation to the amount of residential waste generated as they were lower in 1998 at 1.17 million, and had risen to 1.23 million in 2016 (Census Buerau, 2017).

The tonnage of yard waste and other land clearing debris landfilled in 2016 was 1,367 tons (Figure 18), representing 23.6% of all wood waste landfilled (Table 46). When compared to previous studies, yard waste made up 21.8% of wood waste landfilled per facility with a mean tonnage of 2,461 tons. Therefore, although the proportion increased slightly in 2016, the actual tonnage landfilled per facility decreased from 1998. Yard waste can have many variables including density which can vary due to the presence of dirt and rocks; however, it seems that tonnage rates remain relatively stable year to year.

Facilities were asked about treated wood for the first time in the 2016 study. Treated wood can have different landfilling procedures and desirability than other types of timber. While treated wood only made up 1%, or about 125 tons, of the wood landfilled at C&D facilities, several facilities indicated that 10-20% of wood landfilled was treated wood (Table 46).

Wood pallets and crates made up approximately 5.6% of all wood waste landfilled at C&D facilities in 2016 with each facility landfilling a mean of 324 tons (Table 46). This represents a reduction in the proportion of wood waste that was pallets and crates in 1998 when they totaled 9.5% of all wood waste landfilled. However, the actual tonnage of pallets and crates landfilled in 1998 was much higher at 1,075 tons (Corr *et al.*, 2000).

Table 46 Mean wood waste landfilled per facility by category in 1998 and 2016 (Bush, Araman and Corr, 2001). A (*) Denotes that this category was not tracked in 1998.

Wood Category	1998		2016	
	Percent of Wood Waste	Mean Tonnage of Wood Waste per Facility	Percent of Wood Waste	Mean Tonnage of Wood Waste per Facility
Yard Waste	21.8%	2,461	23.6%	1,367
Residential	32.9%	3,715	24.3%	1,411
Industrial	29.3%	3,309	44.8%	2,596
Pallets and Crates	9.5%	1,075	5.6%	324
Other	6.5%	730	0.3%	19
Treated Wood*	-	-	1.4%	82

Wood Pallets and Crates Landfilled

The percentage of facilities accepting wood pallets for landfilling in 2016 was 85.5%, representing a 14% increase since the previous Virginia Tech of 1998 which found that 71.5% of facilities accepted wood pallets for landfilling (Figure 19).

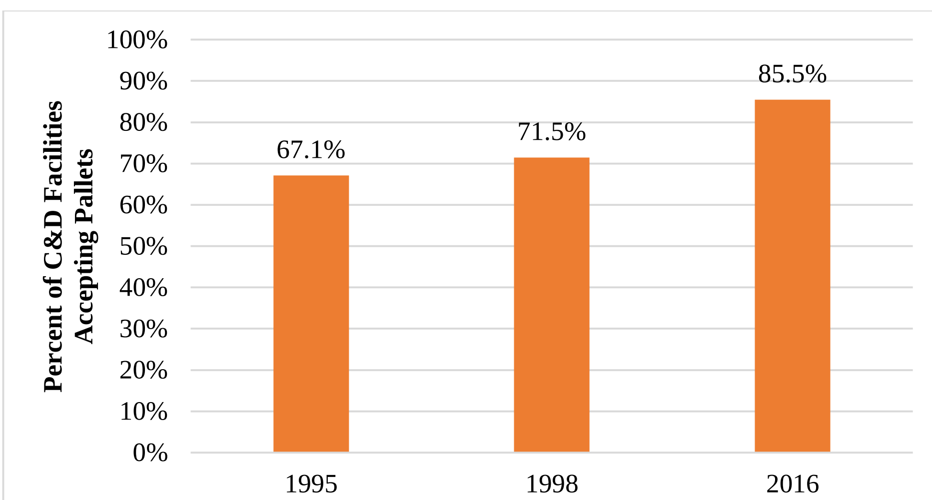


Figure 19

This may suggest that facilities which have restrictions on wood pallet landfilling have been exiting the market or that technological improvements have allowed facilities to expand their capabilities, thus removing barriers to the acceptance of wood pallets for landfilling.

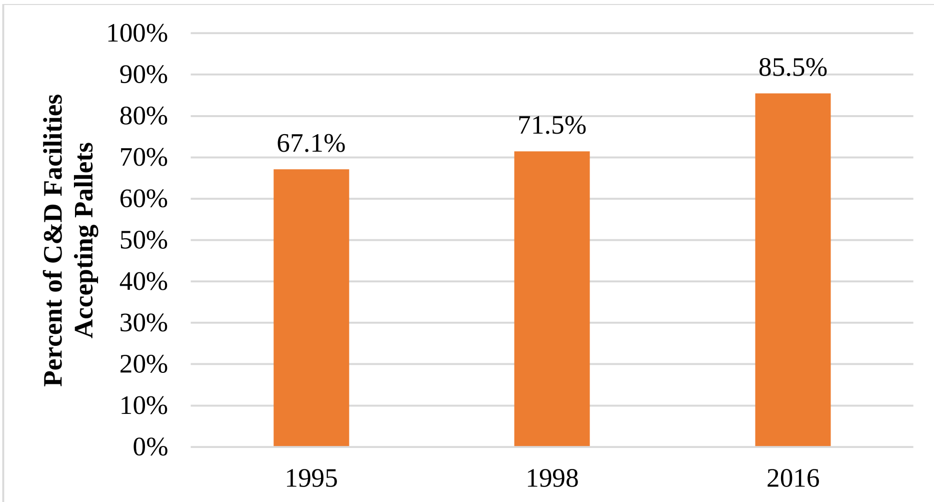
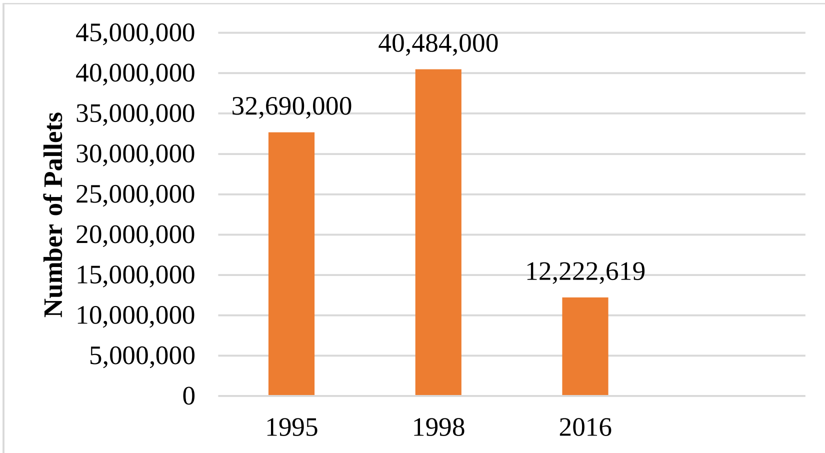


Figure 19 Percentage of C&D facilities that accepted pallets for landfilling in 1995, 1998, and 2016.

There were over 12.2 million pallets landfilled at C&D facilities in the United States in 2016. This represents a 69.8% reduction from the 40.5 million pallets landfilled in 1998 (Figure 20). This is a positive finding for construction management programs because it shows that they are improving control of their waste streams. It is also good for C&D landfills because it shows that they are conserving space and potentially using these materials to add value to their operations.

Figure 20 Total number of pallets landfilled at US C&D landfills in 1995, 1998, and 2016



Pallets and crates made up 0.43% of the total waste received at C&D landfills in 2016 (Table 47). This is a decrease from the results of the 1995 and 1998 studies, which found that pallets made up 2.1% and 3.3% of the total waste received. The reason for this is that the total amount of C&D waste generated has gone up, while the total tonnage of pallets landfilled at each facility has decreased since 1998. This means, overall, fewer pallets were sent to landfills. Construction sites may be generating less pallet waste or sorting them prior to disposal. Because the percentage of landfills accepting wood pallets for disposal has increased, it is not likely that the landfills are restricting the acceptance of pallets any more than in previous years.

Table 47 Total tonnage and number of pallets landfilled in 1995, 1998, and 2016. Mean percent of total waste that was comprised of landfilled pallets.

Year	Mean Percent of Total Waste Received	Total Amount of Pallets Landfilled (Tonnage)	Total Number Pallets Landfilled
2016	0.43%	336,122	12,223,000
1998	3.29%	1,113,250	40,484,000
1995	2.12%	894,461	32,690,000

Recovery at C&D Facilities

It was found that 40.3% of all C&D landfills in the United States operate wood recovery areas, which was a 10.7% increase from 1998 (

Table **48**). While 7% of facilities indicated that they planned on adding wood recovery operations in 1998, none indicated that they were planning to in the 2016 study. Based on these results, it would appear that facilities that had recognized the opportunities in recovering wood waste made the modifications during the late 1990's, and the facilities that have not done so by now likely do not realize the value in doing so. This indicates that the market for wood waste recovery is more mature than it was in 1998 when there were rising volumes of wood waste year to year and fewer facilities that had invested the capital required to start a wood recovery operation.

Table 48 Materials that C&D facilities are able to recover currently or are planning to add within two years for 1998 and 2016. (*) Denotes that this category was not tracked in previous surveys.

	1998		2016	
Material	**Now**	**Two Years**	**Now**	**Two Years**
Asphalt	28.4%	2.3%	32.3%	3.2%
Brick	28.4%	2.3%	37.1%	0.0%
Concrete	35.4%	3.1%	54.8%	3.2%
Gypsum Wallboard	8.2%	3.5%	17.7%	0.0%
Metals	53.7%	2.7%	64.5%	1.6%
Plastics	18.3%	3.9%	24.2%	0.0%
Roofing Materials	8.9%	4.7%	16.1%	6.5%
Treated Wood	*	*	11.3%	1.6%
Wood (other than pallets)	29.6%	7.0%	40.3%	0.0%
Wood Pallets	27.0%	13.0%	33.9%	1.6%

Whether facilities have the ability to recover wood pallets was one of the main questions that this study attempted to answer. Nationally, the percentage of facilities with the ability to recover pallets increased from 27% in

1998 to just under 33.9% in 2016. Although, in 1998, 13% said they planned on adding pallet recovery operations within two years, by 2016 only 6.9% had done so (

Table **48**). This may indicate that some facilities which had hoped to do so found some barriers to starting a wood pallet recovery operation. Starting recovery may have hindered profitability or the facility may not have had the necessary labor or capital to do so.

Respondents were asked to elaborate on the barriers to pallet recovery and recycling in the C&D waste stream that they encountered, and they provided a range of answers. The most common answer was that pallets generally arrive unsorted and mixed with other wastes and the value of the labor and equipment required to sort the pallets from other types of waste was too high given the low value that the pallets could be sold for. Facility compliance, contamination, and available equipment were also listed as barriers to the recovery and reuse of pallets. Despite this, some respondents said that there were no barriers, and that they utilize pallets for a variety of purposes as can be seen in the following results.

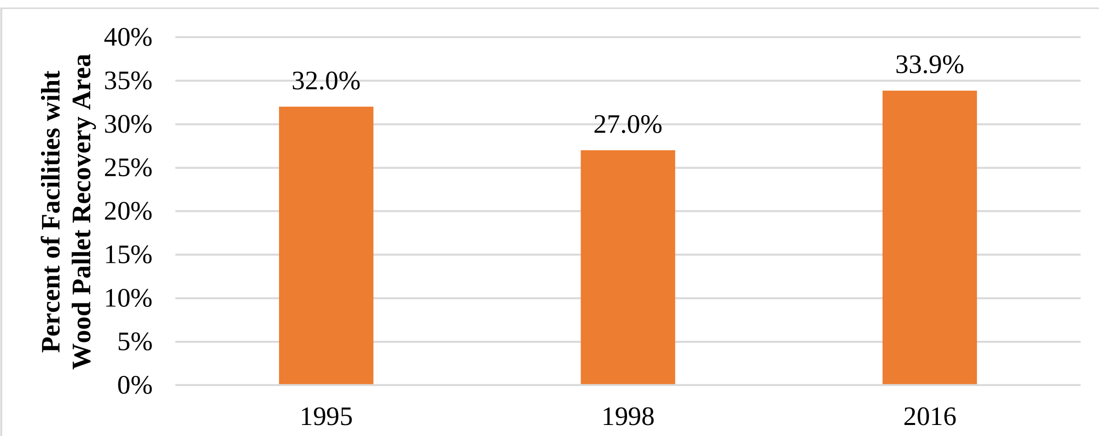


Figure 21 Percentage of US C&D facilities operating wood pallet recovery areas in 1995, 1998, and 2016.

C&D landfills recover wood from a variety of different sources. The largest source of recovered wood waste for C&D landfills is from yard and land clearing wood debris, which made up 85% or 19,393 tons of all recovered wood (Figure 22). Yard and land clearing wood debris is easy to recover because it typically does not contain metal, chemicals, or other problematic materials. If the yard waste contains significant amounts of dirt or leaves, it increases the weight, causing it to comprise a greater portion of the total tonnage (Turley *et al.*, 2000).

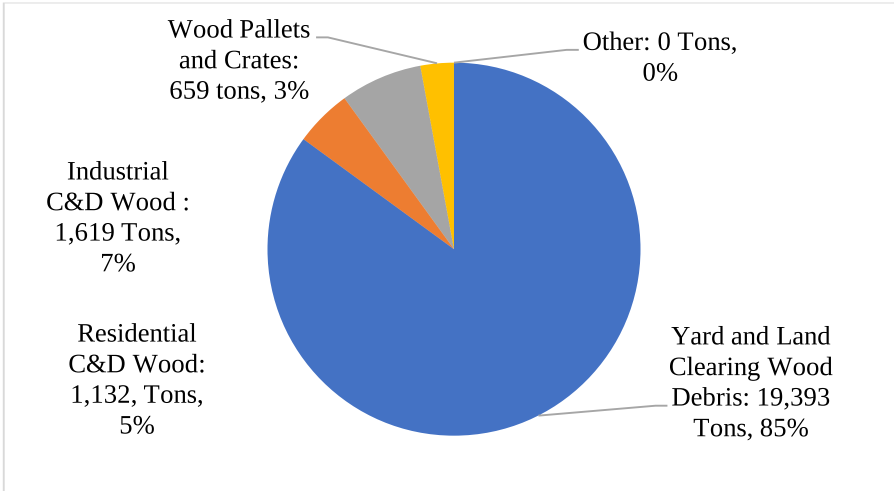


Figure 22 Total national wood waste recovered by category at C&D facilities in 2016.

Industrial and Residential waste streams made up 12%, or 2,751 tons of recovered wood accepted per C&D facility. Industrial wood waste made up a slightly larger portion of the recovered wood waste at 7% with the other 5% coming from residential wood waste. An additional 3% of the waste received at each facility is comprised of wood pallets and crates, equivalent to a mean of 659 tons per facility.

When compared to the 1998 study, there was a significant change in the percentages of total wood waste for which each category was responsible. The amount of yard waste increased from 27% to 85%, and the amount of "other" wood waste decreased from 40% in 1998 to 0% in 2016 (Table 49). These was also a decrease in the proportion of recovered waste that was industrial and residential waste. One possible explanation for this is that the mean tonnage of wood waste recovered per C&D facility has increased 292% since 1998. When analyzing the tonnages in each category of wood waste that the typical C&D landfill receives, the change in total tonnages is less significant than the change in percentages.

Table 49 Mean wood waste recovered per facility by category at US C&Ds landfill in 1998 and 2016

	Mean Wood Waste Recovered by Category			
	1998		2016	
	Percent	Tonnage	Percent	Tonnage
Yard Waste	27%	3,195	85%	19,393
Residential	25%	2,959	5%	1,132
Industrial	20%	2,367	7%	1,619
Wood Pallets and Crates	24%	2,840	3%	659
Other	40%	4,734	0%	0

The increase in the tonnage of wood waste recovered along with the decrease in wood waste landfilled indicates that a much greater portion of the total wood waste received at C&D landfills is being recovered, and less is being landfilled. This could be explained by maturing markets that have an increased demand for recovered materials and an advancement in facility technology, such as vibrating multi deck screens, that facilitate the sorting of wood and other earthen materials (Goldstein, 2006). Historically, the amount of wood waste recovered each year has increased since 1995 (Figure 23).

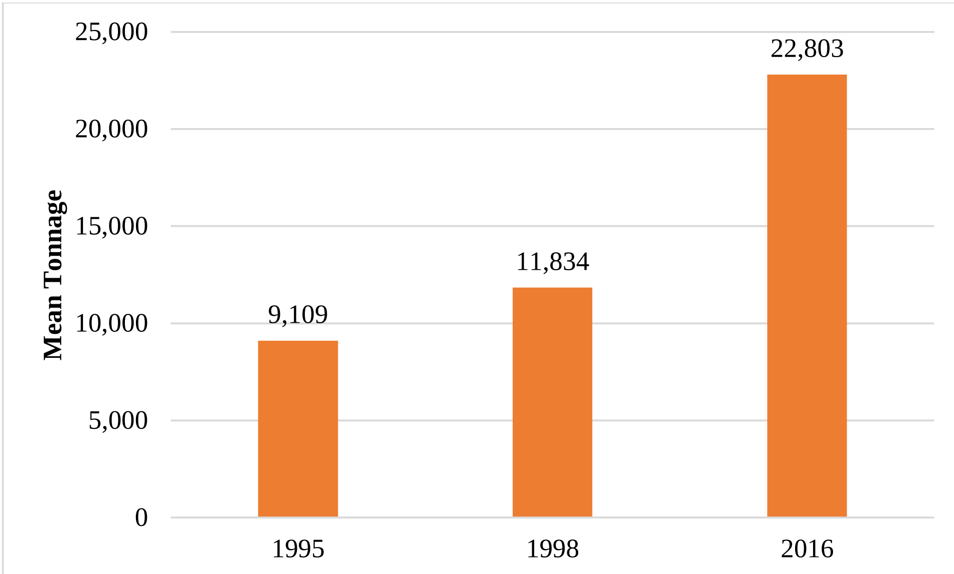


Figure 23 Mean wood waste recovered per facility in 1995, 1998, and 2016

The national estimate for total wood recovered at US C&D landfills in 2016 was 23.7 million tons (Figure 24). This is a significant increase in wood recovered compared to 1998, largely due to the increase in total mean tonnage at each facility. This is a strong indicator that facilities have taken great efforts to divert wood waste from being landfilled and to find additional sources of value through the utilization of it since 1998, when the last survey was conducted.

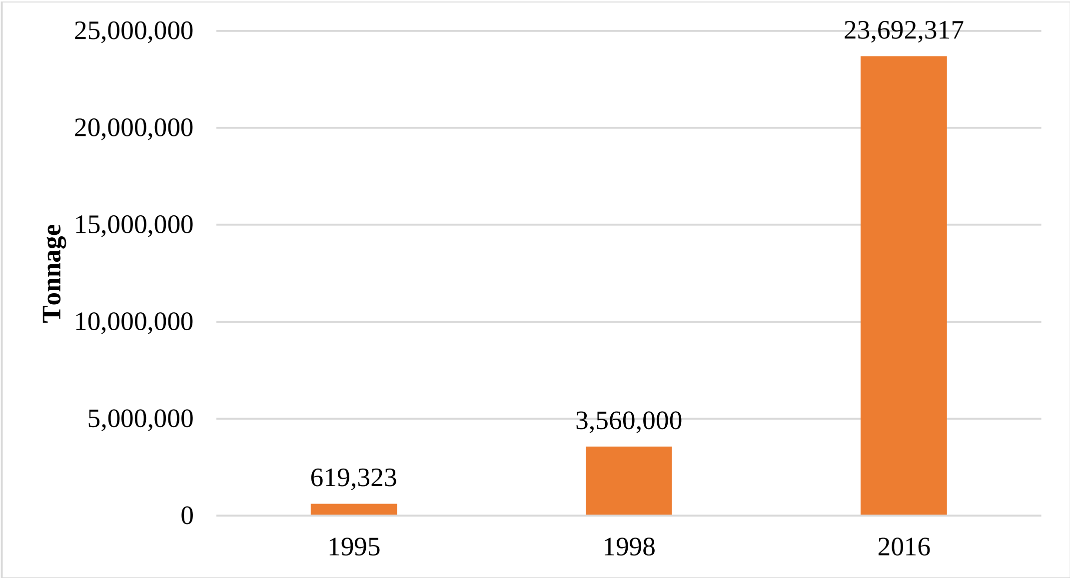


Figure 24 National estimate for total amount of wood recovered at US C&D landfills.

C&D Wood Pallet Recovery

The total number of pallets recovered has increased since 1998 by 56.7% (Figure 25). While still a sizeable increase, the number of pallets recovered did not grow nearly as much as the amount of wood waste recovered at C&D facilities. When the number of pallets recovered and landfilled are combined, it can be seen that the overall number of pallets received at C&D facilities decreased from 1998 to 2016. But, the proportion of total pallets that were recovered increased from 28.2% in 1998 to 67.1% in 2016 (Figure 26).

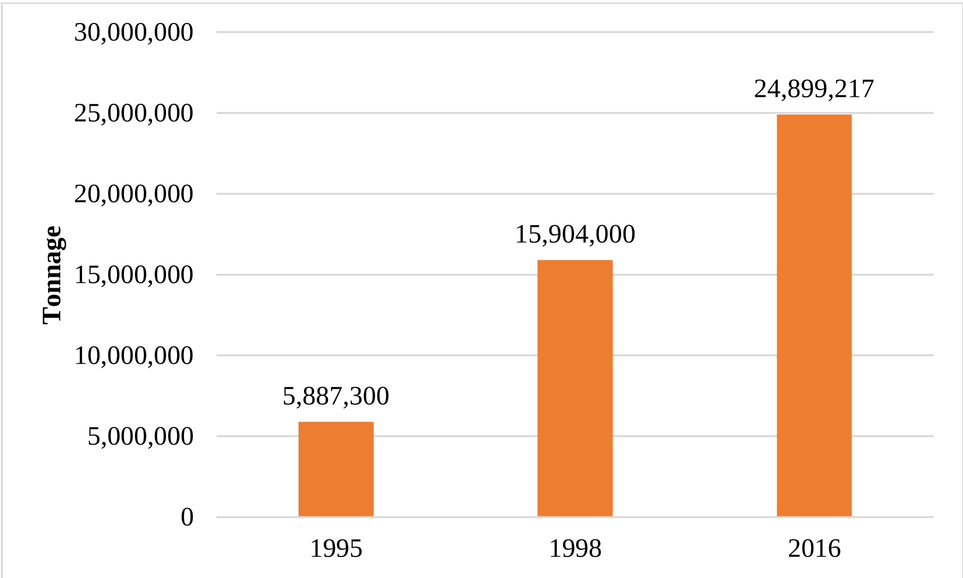


Figure 25 Total number of pallets recovered at C&D landfills in 1995, 1998, and 2016. Assumes 55lbs per pallet.

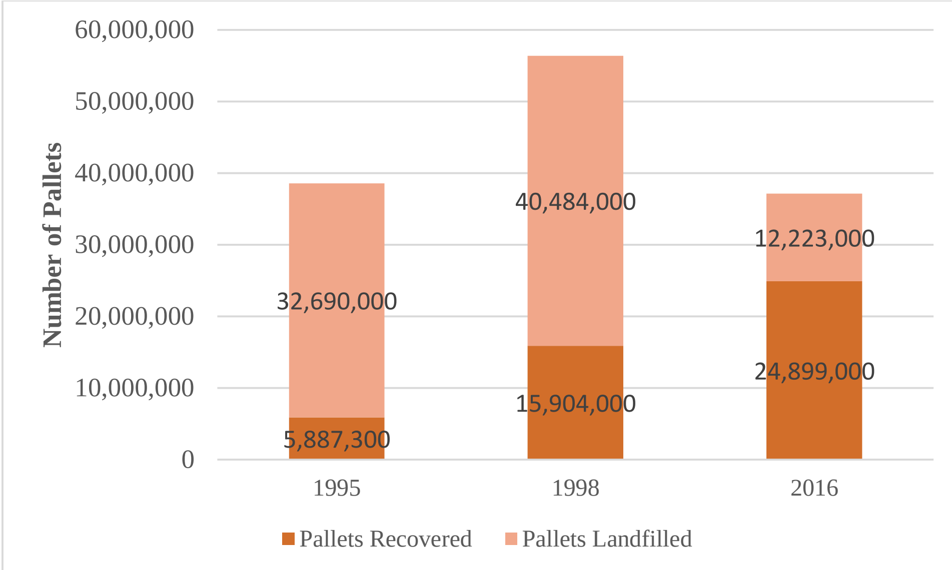


Figure 26 Total number of pallets landfilled and recovered at C&D facilities in 1995, 1998, and 2016. Assumes 55lbs per pallet.

Several facilities provided data on the sale of chipped or ground wood at their C&D landfills. In an effort to promote more responses, the categories for use of the wood chips were condensed from many specific uses into three categories based on the type of customer it was sold to. These included commercial use, residential use, and other. The average price per ton for commercial use was $19.10 while the price for chipped wood sold to residential customers was slightly lower at $17.91 (Table 50).

Table 50 Average cost per ton (USD$) and tonnage sold for chipped or ground wood at C&D facilities that sold ground and chipped wood.

Category of Use	$/Ton	Tonnage
Commercial Use	$19.10	N/A
Residential Use	$17.91	2,466
Other Uses	$8.83	12,624

One-fifth of landfills indicated that they separate out pallets to be recovered, while none indicated that they repair pallets or utilize pallet repair operations (Table 51).

Table 51 Percentage of US C&D landfills that separated pallets from other types of wood at their recovery areas.

Category	Percentage of Respondents
Yes, for other uses	20%
Yes, for repair	0%
No	80%
TOTAL	100%

4.4 Conclusions

1. The total amount of waste received at all C&D facilities in 2016 was 77.8 million tons. This is an increase from the 40.3 million tons received in 1998 and the 42.2 million tons in 1995. This increase aligns with results of the EPA studies which show an increase in the amount of C&D waste generated over the same timeframe (United States Environmental Protection Agency, 2015).
2. Overall, the tonnage of wood waste received at C&D landfills has increased from 19.8 million tons in 1998 to 29.7 million in 2016. However, during the same period, the amount of wood landfilled has decreased from 16.2 million tons to 6 million tons, and the amount of wood waste recovered has increased from 3.6 million tons in 1998 to 23.7 million tons in 2016.
3. The total number of pallets received at C&D landfills decreased from 56.4 million in 1998 to 37.1 million in 2016. In 2016, 12.2 million pallets were landfilled and 24.9 million pallets were recovered or put to other uses while in 1998, 40.5 million pallets were landfilled and 15.9 million were recovered. Overall 67% of pallets received at C&D facilities were recovered in 2016, which is a significant increase from the 28.2% that were recovered in 1998.
4. In 2016, there were 508 million new pallets and 341 million repaired pallets produced throughout the United States (Gerber 2016). Thus a total of 7.3% of all new pallets produced in 2016 ended up at Construction and Demolition landfills while only 2.4% of all new pallets produced were landfilled and 4.9% were recovered or repurposed.

4.5 References

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Chapter 5: Summary, Conclusions and Recommendations for Future Research

The purpose of this research as to determine the amount of wood and wood packaging waste going to Municipal Solid Waste (MSW) landfills and Construction and Demolition (C&D) landfills within the continental United States. This was accomplished through gathering a list of landfills from publicly available sources and sending them a mailed questionnaire that included the option for it to be completed online. After completing the research, it was found that:

1. The total amount of wood received at MSW and C&D landfills was 46.9 million tons. This is a slight decrease from the 49.6 million tons in 1998. While the rate of wood recovered at MSW facilities increased from 30.0% in 1995 to 33.8% in 1998, the rate of recovery at C&D facilities increased from 18% to 79.7% in the same time period.
2. Overall there were 66.1 million pallets received at MSW and C&D landfill facilities in 2016. This is approximately a 70% reduction from the 216.8 million in 1998 and the 222.6 in 1995 (Corr *et al.*, 2000).
3. Rates of pallet recovery were much higher than they have been with 54.8% of pallets received MSW facilities recovered and 66.1% at C&D facilities. This is a dramatic increase from the 17.3% and 13.8% in 1995 and 1998 at MSW facilities as well as the 13.5% and 28.2% of pallets recovered C&D facilities in 1995 and 1998, respectively.
4. There was a 29% increase in the percentage of MSW facilities operating wood pallet recovery areas; rising from 33.4% in 1998 to 62.4% in 2016. However, the total number of facilities has decreased. In comparison, the percentage of C&D facilities operating pallet recovery areas increased by only 6.9%, but the total tonnage of pallets recovered has increased significantly.
5. In 2016, there were approximately 849 million new pallets produced by pallet manufacturing and repair firms in the United States in 2016; of these, 508 million were new pallets and 341 million were repaired or refurbished (Gerber 2016). It was also found that MSW facilities received 5.7% of these and C&D facilities received 7.3%, for a total of 13% of all new pallets manufactured in a year were sent to MSW or C&D landfills. When the results further broken down, it is apparent that only 5.0% of all new pallets produced being landfilled while 8.0% is recovered into other value adding products at the landfill.

Recommendation for Future Research

There are several recommendations for future researchers that could improve the quality and quantity of responses. It is important to determine the appropriate level of questionnaire detail to survey facilities on and to determine the optimum balance between details and ease of response. While this survey and the previous surveys asked for a very high level of detail, it is likely a better strategy would have been to ask fewer, less specific questions regarding just the key issues. This is because as the questionnaire becomes longer, fewer members of the population participate, thus reducing the response rates. Also, as was indicated by many respondents, there is a limit to the levels of information that facilities track, and these questions draw from estimates. Due to this, this study found that asking percentages and tonnages added a level of complication.

Another issue seen through this research was that many facilities are licensed to receive multiple types of waste, which can include MSW, C&D, and other types of specialty industrial or agricultural waste. Therefore, the questions need to provide a way for facilities to account for these other categories and not make the assumption that all waste a facility receives is MSW, or any other specific type of waste. This study shows large differences in the amount of waste received and recovered between regions. Investigating why this is the case, especially with regards to pallets, could prove beneficial. It is possible that certain types of industrial activity produce more pallets for disposal to landfills. Areas near warehouses or ports may receive more pallets as goods are palletized and depalletized. Designing these factors into future research could help improve accuracy and response rate.

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Appendix A: MSW Statistics

Table 52 Steel-Dwass nonparametric comparison for all pairs of tonnage of MSW waste landfilled per facility by region. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Midwest	.0235*
Northeast	Midwest	0.4078
South	Northeast	0.9986
West	Midwest	0.9984
West	Northeast	0.4088
West	South	.0135*

Table 53 Steel-Dwass nonparametric multiple comparison for all pairs for wood landfilled per facility by region. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Midwest	0.9683
Northeast	Midwest	0.9374
South	Northeast	0.8268
West	Midwest	0.9876
West	Northeast	0.7336
West	South	0.996

Table 54 Steel-Dwass nonparametric comparison for all pairs for pallets landfilled per facility. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Midwest	0.5236
Northeast	Midwest	0.4404
South	Northeast	0.9167
West	Midwest	0.7806
West	Northeast	0.0129*
West	South	.0185*

Table 55 Steel-Dwass nonparametric comparison for all pairs for wood waste recovered per region. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Midwest	.0142*
South	Northeast	0.155
West	Midwest	0.0995
West	Northeast	0.427
Northeast	Midwest	0.9763
West	South	0.7098

Table 56 Steel-Dwass nonparametric comparison for all pairs for total tonnage of pallets recovered per region. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Northeast	0.95
South	Midwest	0.99
Northeast	Midwest	0.99
West	Northeast	0.99
West	Midwest	0.89
West	South	0.71

Table 57 Steel-Dwass nonparametric comparison for all pairs for alternative daily cover (ADC). A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.

Region A	Region B	p-Value
South	Northeast	0.36
South	Midwest	0.95
West	Northeast	0.95
Northeast	Midwest	0.63
West	Midwest	0.81
West	South	0.24

Appendix B: C&D Statistics

Table 58 Steel-Dwass nonparametric multiple comparison for total waste received per facility. A (*) indicates a p-Value lower than .05, indicates a significant difference at a 95% confidence level.at a significance level of .10.

Region A	Region B	Std Err Difference	Z-Score	P-Value
South	Midwest	4.16	2.2	0.1219
South	Northeast	4.95	1.16	0.6553
West	Northeast	2.81	0	1
Northeast	Midwest	2.93	-0.14	0.999
West	Midwest	3.06	-0.32	0.9891
West	South	4.17	-2.02	0.1793

Appendix C: MSW Survey

Investigation of Waste Disposal and Recovery in the United States

Municipal Solid Waste

Wood and Wood Packaging

If you have any questions or concerns about this study, please contact:

Zack Shiner at (484) 340-6120 or Zack7@vt.edu

Please only fill out this survey for the facility where this form was received. Several of the questions require approximations and estimates, we understand that some of this information may not be recorded by your facility so please make your best attempt. If you have questions, please contact us at 484-340-6120 or zack7@vt.edu

Definition of Terms

Recovered waste: Any waste that accepted by your facility that does not go directly into the landfill. Many facilities have a separate area for wood, woody yard waste, and pallets. This waste is commonly chipped for mulch or alternative daily cover.

Normal waste: Unsorted MSW waste.

Wood and Brush: Waste including all wood, treated wood, wood products, woody yard waste, pallets, wooden packaging and crates, and wood from destruction of structures.

Pallets: A flat shipping platform for use by forklifts in the transportation of goods.

Crates and wooden packaging: nailed or locked corner boxes, crates, barrels, baskets, carrier trays, chests, and reels.

Pallet Recycler: A business that collects used pallets for repair, stripping to individual components, or mulching.

1. **This survey is intended for facilities that receive municipal solid waste. Do you accept municipal solid waste at your facility?**

   ☐ Yes______ *Please continue*

   ☐ No ______ *Please stop here and return the questionnaire. Postage is prepaid.*

2. **In which state is your facility located?**

   State: ____________

3. **What is the estimated population that your facility serves?**

   Number of people: __________________

4. **In 2016, approximately how much total waste (all types) was received at the municipal solid waste facility you operate?**

Total waste received (tons)	

5. **In 2016, what was the breakdown of the total waste received at your facility that was landfilled compared to the amount recovered for any other uses (recycling, daily cover, combustion, compost, etc.)?** (Please estimate percentage or tonnage that passed through the scalehouse for the following categories.)

	Percentage		Tonnage
Landfilled – wood and brush			
Landfilled – normal waste		or	
Recovered – wood and brush			
Recovered – normal waste			
Total	100%		

6. **In 2016, what were the average tipping fees for the following waste types received at your facility?** (Leave categories blank if you do not have a tipping fee for that specific type of waste or answer what you would charge.)

	Tipping fee ($/ton)
Landfilled normal waste	
Recovered wood and brush	
Recovered pallets	

7. **In 2016, did your facility accept wood and wood products of any kind for landfilling?**

☐ Yes

☐ No *(please skip to question 20)*

8. **Do you accept wood pallets at your Municipal Solid Waste facility for landfilling as they are received?** (I.e. without additional recovery processing such as grinding, chipping, incineration, or repair.)

☐ Yes

☐ No *(please explain below*)

Please explain why you do not accept pallets for landfilling as they are received:

____

____

9. **In 2016, what were the estimated amounts of wood <u>landfilled</u> by the following categories?** (Please fill out either tonnage landfilled or percentage of total wood landfilled.)

	Percentage		Tonnage
Pallets			
Crates or other wood packaging			
Construction related wood		or	
Treated Wood			
Woody yard waste (stumps, logs, brush, etc)			
% Other (furniture, household goods, etc.)			
Total	100%		

RECOVERY AND RECYCLING

10. **Does your facility have the ability to recycle or repurpose wood, yard waste, or wood pallets? In other words, does your organization divert wood waste into a separate area for recovery?**

☐ Yes…*Please continue with this section*

☐ No…*but we plan to within the next two years (please skip to question 17)*

☐ No…*and we do not plan to add any recovery operations (please skip to question 17)*

11. **In 2016, approximately what was the breakdown by the following categories of wood and yard waste received at your <u>recovery area</u>?** (Please answer either percentage or tons of total wood and yard waste processed.)

	Percentage		Tonnage
Pallets			
Crates or other wood packaging			
Construction related wood		or	
Woody yard waste (branches, logs, brush, etc.)			
Other (furniture, household goods, etc.)			
Total	100%		

12. **In 2016, how much of the wood and yard waste received at your recovery area was used for alternative daily cover or facility operation?**

Tons	

13. **In 2016, what was the average selling price and amount of ground or chipped wood sold from your recovery area?** (Please indicate the dollars per ton and the number of tons sold for each category.)

	$/ton		Tonnage
Ground and sold for commercial use			
Ground and sold for residential use		**<u>and</u>**	
Sold for other uses			
Total	100%		

Please explain other uses wood diverted to your recovery area was sold for:

____

____

☐ We did not sell this type of material to residents or businesses in 2016

14. In 2016, did you separate pallets from other types of wood waste diverted to your recovery area? (Please check all that apply.)

☐ Yes…*we repair/recycle pallets*

☐ Yes…*we sell to a pallet recycler*

☐ Yes…*for other uses (please explain below)*

☐ No *(please skip to question 17)*

Please describe other uses for separated pallets:

____

____

15. How has the volume of wood pallets recovered at your wood/yard waste recovery area changed over the past two years?

% Increase	
Or	
☐ *% Decrease*	☐

☐ *No change*

☐ *Our wood/yard waste recovery area has been in operation for fewer than two years.*

16. In 2016, what was your average selling price for pallets and how many did you sell? (Please indicate the average price per pallet sold and the number of pallets sold from each category and leave a section blank if you did not indicate that you do so in the question above.)

	$/pallet		# of pallets
Repaired pallets			
Unrepaired sold to recycler		**and**	
Other uses			

☐ We did not sell pallets in 2016

17. Does your facility convert any of the waste you receive to energy that would have otherwise been landfilled?

☐ Yes

☐ No *(please skip to question 20)*

18. **What was the tonnage of waste that your facility converted to energy that would have otherwise been landfilled?**

Tonnage	

19. **What estimated portion of the amount of waste stated in question 17 was wood?** (Please do not include paper or cardboard.)

% Wood Waste	
or	
Tonnage	

20. **If you would like to receive a summary report of this study, please write your name and a valid mailing and/or email address or attach a business card so we can send it to you upon completion.**

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Thank you for your participation. Your response will help a graduate student to finish his degree. After completing the survey to the best of your ability, please fold the booklet in half and place it in the 9” x 6” pre-paid return envelope. All responses are confidential.

Appendix E: C&D Survey

Investigation of Waste Disposal and Recovery in the United States

<u>Construction and Demolition</u>

<u>Wood and Wood Packaging</u>

If you have any questions or concerns about this study, please contact:

Zack Shiner at (484) 340-6120 or Zack7@vt.edu

Please only fill out this survey for the facility where this form was received. Several of the questions require approximations and estimates, we understand that some of this information may not be recorded by your facility so please make your best attempt. If you have questions, please contact us at 484-340-6120 or zack7@vt.edu

Definition of Terms

<u>Recovered waste</u>: Any waste that accepted by your facility that does not go directly into the landfill. Many facilities have a separate area for wood, woody yard waste, and pallets. This waste is commonly chipped for mulch or alternative daily cover.

<u>Normal waste</u>: Unsorted MSW waste.

<u>Wood and Brush:</u> Waste including all wood, treated wood, wood products, woody yard waste, pallets, wooden packaging and crates, and wood from destruction of structures.

<u>Pallets:</u> A flat shipping platform for use by forklifts in the transportation of goods.

<u>Crates and wooden packaging:</u> nailed or locked corner boxes, crates, barrels, baskets, carrier trays, chests, and reels.

<u>Pallet Recycler</u>: A business that collects used pallets for repair, stripping to individual components, or mulching.

1. This survey is intended for facilities that receive construction and demolition waste. Do you accept construction and demolition waste at your facility?
   - ☐ Yes______ *Please continue*
   - ☐ No ______ *Please stop here and return the questionnaire. Postage is prepaid.*

2. In which state is your facility located?

State: _______________

3. What is the estimated population that your facility serves?

Number of people: ____________________________

4. **In 2016, approximately how much total waste (all types) was received at the construction and demolition facility you operate?**

Total waste received (tons)	

5. **In 2016, what was the breakdown of the total waste received that was landfilled compared to waste that was recovered for any other uses (recycling, daily cover, incineration, compost, etc.)?** Please estimate the percentage or tonnage that passed through the scalehouse for the following categories.

	Percentage		Tonnage
Landfilled – wood and brush			
Landfilled – normal waste		or	
Recovered – wood and brush			
Recovered – normal waste			
Total	100%		

6. **In 2016, what were the average tipping fees for the following materials?** (Leave categories blank if you do not have a tipping fee for that specific type of waste or provide the fee you would charge if that type of waste arrived at your facility)

	Tipping fee $/Ton
Unsorted waste	
Presorted waste	
Sorted wood and brush	
Recovered pallets	

7. **Do you accept wood and wood products at your facility for landfilling?**

☐ Yes

☐ No *(please skip to question 10)*

8. **Do you accept wood pallets at your Construction and Demolition facility for landfilling as they are received?** (i.e. without additional processing such as grinding, chipping, incineration, or repair)

☐ Yes

☐ No

Please explain why you do not accept pallets for landfilling as they are received: ____
____

9. **In 2016, how would you estimate the wood waste <u>landfilled</u> was split among the following categories?** (Please answer in either tonnage landfilled or percentage of total wood landfilled.)

	Percentage		Tonnage
Yard and Land Clearing Wood Debris			
Residential Construction and Demolition Wood			
Industrial Construction and Demolition Wood		or	
Treated Wood			
Wood Pallets and Crates			
Other			
Total	100%		

RECOVERY AND RECYCLING

10. Please select from the list of materials below that your facility is able to recover or is planning on being able to recover in the next two years:

Recover now?

- ❑ Asphalt
- ❑ Brick
- ❑ Concrete
- ❑ Gypsum Wallboard
- ❑ Metals
- ❑ Plastics
- ❑ Roofing Materials
- ❑ Treated Wood
- ❑ Wood (other than pallets)
- ❑ Wood Pallets

Begin to Recover in next two years?

- ❑ Asphalt
- ❑ Brick
- ❑ Concrete
- ❑ Gypsum Wallboard
- ❑ Metals
- ❑ Plastics
- ❑ Roofing Materials
- ❑ Treated Wood
- ❑ Wood (other than pallets)
- ❑ Wood Pallets

11. Does your facility have the ability to recycle or repurpose wood and/or wood pallets? In other words, does your organization divert wood waste into a separate area for recovery?

- ☐ Yes…*Please continue with this section*
- ☐ No…*but we plan to within the next two years (please skip to question 18)*
- ☐ No…*and we do not plan to add recovery operations (please skip to question 18)*

12. In 2016, approximately what was the breakdown of materials for wood received at your <u>recovery area</u>? (Please answer either percentage or tons of total wood waste processed.)

	Percentage		Tonnage
Yard and Land Clearing Wood Debris			
Residential Construction and Demolition Wood			
Industrial Construction and Demolition Wood		or	
Wood Pallets and Crates			
Other			
Total	100%		

13. In 2016, how much of the wood waste received at your recovery area was used for alternative daily cover or facility operation?

Tons	

14. In 2016, what was the average selling price and amount of ground chipped wood sold from your recovery area? (Please indicate dollars per ton and the number of tons sold for each category.)

	$/ton		Tonnage
Ground and sold for commercial use		and	
Ground and sold for residential use			
Sold for other uses			

Please list other uses that wood diverted to your recovery area was sold for: ____
____

☐ We did not sell this type of material to residents or businesses in 2016

15. Do you separate pallets from other types of wood waste diverted to your recovery area? (Please check all that apply.)

☐ Yes…*we repair pallets*
☐ Yes…*we sell to a pallet recycler*
☐ Yes…*for other uses (please explain below)*
☐ No *(please skip to question 18)*

Please describe the other uses for separated pallets:
____
____

16. How has the volume of wood pallets recovered at your C&D waste recovery facility changed over the past two years?

% Increase	
or	
% Decrease	

☐ No Change

☐ Our C&D waste facility has been in operation for fewer than two years

17. In 2016, what was your average selling price for pallets <u>and</u> how many did you sell? (Please leave sections blank if you did not indicate that you do so in the question above.)

	$/pallet		# of pallets
Repaired pallets		<u>and</u>	
Unrepaired sold to recycler			
Other uses			

18. In your opinion, what is the biggest barrier to increased rates of recovery of pallets and similar wood packaging?

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19. If you would like to receive a summary report of this study, please write your name and a valid mailing and/or email address or attach a business card so we can send it to you upon completion.

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Thank you for your participation. Your response will help a graduate student to finish his degree. After completing the survey to the best of your ability, please fold the booklet in half and place it in the 9” x 6” pre-paid return envelope. All responses are confidential.

Appendix F: Follow up Postcard

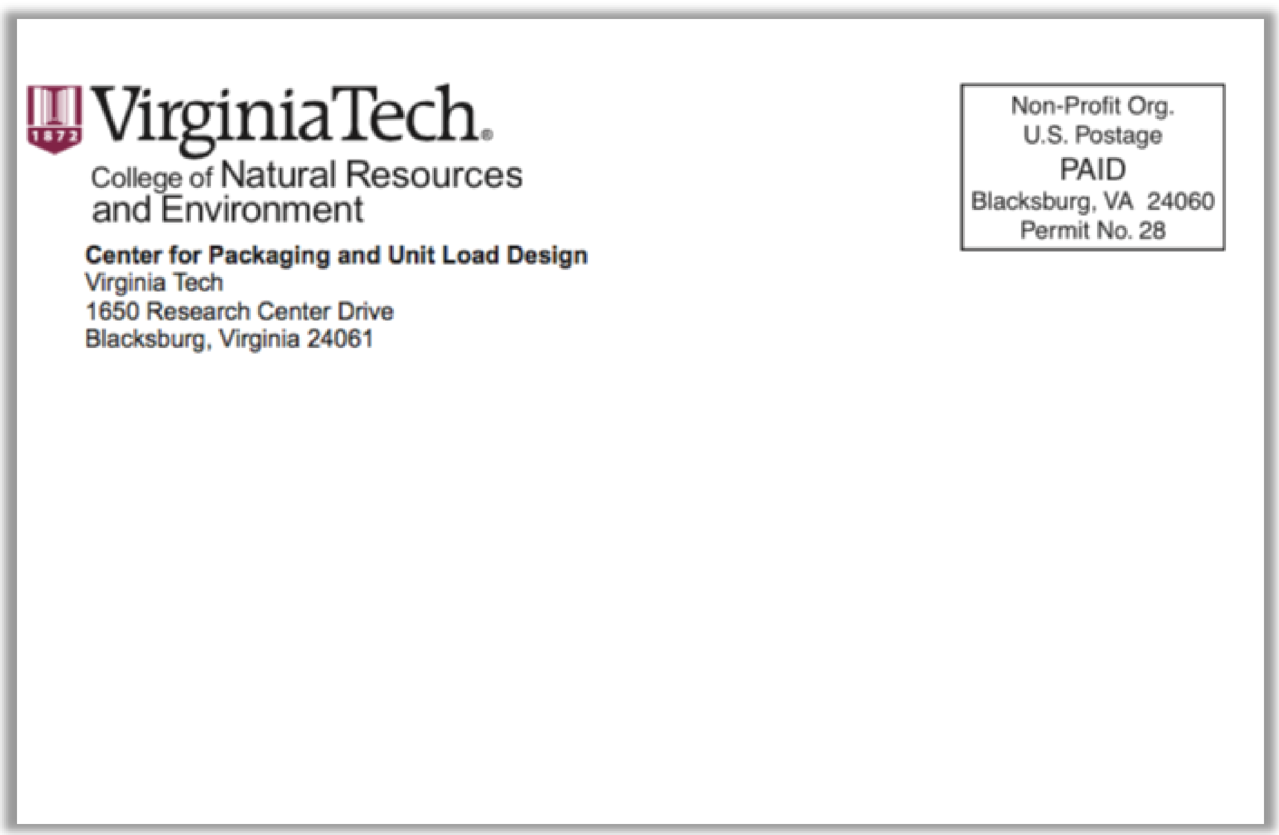

Figure 27 Follow up postcard sent to non-respondents (front)

Dear Sir/ Ma'am,

Please help! You were recently sent a copy of a questionnaire focusing on wood and wood packaging waste being landfilled and recovered in the United States. I am reaching out to you to ask for your help by completing and returning the questionnaire or completing it online at:

www.vtlandfillsurvey.org

Your unique ID: xxxxx

The information generated from this study will inform trade groups and policy makers of important trends in waste as well as wood product use and recovery. **It will also help me graduate!**

All of your responses are confidential. If you have any questions regarding this study, please contact me at zack7@vt.edu.

Thank you for your help,

Zack Shiner
MS Candidate
Department of Sustainable Biomaterials
Virginia Tech

Figure 28 Follow up postcard sent to non-respondents (back)