



Residential C&D Waste Study

PREPARED

IN COOPERATION WITH THE HOUSTON-GALVESTON AREA COUNCIL AND TEXAS
COMMISSION ON ENVIRONMENTAL QUALITY

By

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Executive Summary

I. Overview

Construction and demolition (C&D) waste accounts for an enormous amount of the waste stream in the United States. While most of this waste accrues to landfills, estimates are that 90 percent of the waste stream is potentially reusable or recyclable. There are two main approaches and a third emerging practice for systematically addressing the C&D debris cycle.

1. *Central Processing Facility*: Transporting of mixed C&D waste to a central processing facility where high graded material is sorted from the debris. The mixing of the reusable materials with other debris such as nails, paint, oil or plastic can limit their potential to be recycled due to contamination.

2. *Job Site Material Recovery*: Separation of selected materials at the job site followed by transporting the materials directly to the markets for those materials. This approach can result in a larger amount of material recovered but is a less common practice due to factors such as lack of experience with this method, lack of on site space and the timeline set for building completion.

3. *On-site Material Processing*: This emerging method consists of processing selected materials for end of life use at the job site. It takes tactics from the two main approaches and deploys the technology to the site through on-site grinding using a portable residential scale grinder. This technique is inspired by the biological notion that waste equals food. The concept of waste equals food is exhibited by nature every day and human emulation of such concept can enhance nature's abilities.

II. C&D waste mitigation and salvage

Cities and agencies throughout the United States have successfully employed numerous waste mitigation strategies for C&D waste. Contractor strategies, building code specifications, and a practice called "optimum value engineering" can all help to minimize the C&D waste stream. Methods such as deconstruction rather than demolition, "efficient framing" and city adoptions of reduction goals have also shown to greatly reduce the C&D waste stream. Most important perhaps is the policy prospective of the political jurisdiction that operates the landfills.

III. Reuse and recycling options for C&D debris

There are many options and applications of the recyclable material generated by building sites. These include use as an industrial fuel source, mulch in composting operations, animal bedding, soil amendment and reuse as building materials. Material such as gypsum board (which many landfills are prohibiting from entering) can be ground up and used in many different ways such as in the making of Portland cement or as recycled content for new drywall. There are also many resale stores in the H-GAC area that accept building materials and salvaged parts for resale to the public. Also a nonprofit organization Historic Houston does the ultimate recycling by accepting a limited number annually of whole houses for redeployment.

IV. C&D debris regulations

C&D waste is mainly regulated on a state-by-state basis with requirements and facilities varying widely. Because of growing awareness that C&D debris can contain hazardous materials, some states are in the process of revising their C&D debris regulations to minimize or eliminate the amount entering their landfills. Policies are also being implemented throughout the nation to encourage C&D recycling. A growing threat to C&D debris recycling is the increase in franchise agreements between demolition contractors and municipalities around the country. These agreements result in a decreased flow of C&D waste and other debris to waste recyclers. There are many best practices steps that local and state governments can take to encourage C&D debris recycling including (but not limited to) implementing policy, providing tax incentives, rebates, sales tax exemptions and low interest loans to recycling businesses.

Specifics for Texas

C&D waste comprises about 22% of the total Municipal Solid Waste (MSW) stream in the state of Texas and 38% of the total waste stream in the thirteen county H-GAC region. There is an abundance of land dedicated to solid waste disposal and so, if compared to the rest of the nation, it remains very inexpensive to own and operate a MSW facility in Texas. Texas has regulations for licensed landfills and effectively monitors them to the fullest of their capabilities. Left for municipalities to deal with is a large amount of non-licensed dumpsites.

The Houston Advanced Research Center (HARC) hosted a roundtable May 26, 2005 to discuss both the perceived barriers and disincentives to the implementation of C&D waste recycling programs and public outreach materials. In attendance were representatives from varied organizations, contractors, builders, engineers, the recycle and salvage industry, landfill industry, remodelers, architects and the community. Such barriers that arose were as follows: an abundance of inexpensive land, tradition, price and cost confusion, uneducated trades and builders, lack of communication with political representatives, big powerful lobbies, few positive public and private models and a lexicon of confusion.

V. C&D Waste Stream Audit

The Houston Advanced Research Center contracted with the Houston-Galveston Area Council (H-GAC) to conduct a residential waste study by performing waste stream audits of two sites. Working the Tom Cox Builders, Inc., HARC audited the waste stream of two large custom house projects and applied an on-site material processing technique to the second site. The two houses were of similar size and constructed by the same builder and sub contractors.

The project was documented photographically and a manual logging system was used to identify material and volumes. HARC utilized a calculator frequently cited by the Environment Protection Agency (EPA) which adapted it from a National Association of Home Builders (NAHB) research project to calculate predicted weights of waste container content. Found throughout the study was the varying weight of containers depending on the method used to pack them.

The audit for the first house began in earnest on May 26, 2004 when Browning Ferris Inc., (BFI) delivered the two large 30 cubic yard containers on the site. The plan was two fold, to first estimate the volume and weight of containers and then run the container over the scales full and empty to obtain the actual weights. A total of nine hauls were conducted between July 12, 2004 and January 5, 2005. Of the nine hauls, three consisted of wood material only, one of drywall only and five of commingled material. The total volume of the nine hauls combined was 266 cubic yards and weighed a total of 85,242 pounds.

The second house was approached from the onset with the plan of dramatically reducing the amount of waste going to the landfill. After evaluating different possibilities, the methodology of on-site grinding was chosen due to this house being a large custom home. The volume reduction from bulk waste to ground waste was a little more than a 3 to 1 ratio and the materials were applied as a soil or site improvement material. In house one the builder had to purchase crushed concrete, mulch and fill for the lot while in house two, the reuse of the ground material served this purpose and no extra material had to be bought.

Because on-site grinding can not address every need in the new construction waste stream, a 30 cubic yard container was placed on site to handle the material that could not be ground. A total of three hauls (as opposed to nine) were the result of the non-grindable material. The debris in these hauls consisted of packaging, sheathing, brush, TechShield, mortar and understory clearing. The total volume of the three hauls combined was 90 cubic yards and weighed a total of 13,220 pounds. Clearly the plan to reduce the amount of waste going to the landfill was very successful. The economics of C&D waste disposal in Harris County are such that at the present time using conventional cost benefit analysis it is not economically feasible to believe that on-site grinding is a viable option. Our landfill rates (\$ 6.00 cubic yard) would have to basically double for the conventional cost benefit analysis to support on-site grinding.

The research demonstrated that the residential C&D waste stream is substantial for large custom homes. The research also demonstrated a manner in which the residential C&D waste can be diverted from the landfills. The research however was focused on the smallest sector of the smallest segment of the C&D waste stream. This doesn't imply that residential new construction is unimportant, but it does raise some serious questions about what is known about residential renovation and demolition practices, policies, barriers, and market-based potential solutions.

I. Overview

A study conducted for the Environmental Protection Agency found that 136 million tons of debris was generated in 1996 by construction and demolition (C&D) waste. This remains the most exhaustive national study available. C&D waste in this study was defined as debris from the following structures; both residential and non-residential buildings, roads, and bridges (Franklin Associates, 1998:ES-2). The residential component of those 136 million tons of debris was 43% of the waste or (58 million tons per year). The fact that the non-residential waste stream is larger than the residential should not come as a surprise due to the scale of America's buildings. The surprise may come in the distribution of waste across the categories of activity. Demolitions account for 48% of the waste stream and renovation activity accounts for 44%. This leaves a paltry 8% of the waste stream attributable to new construction. In the residential only realm the renovation activity accounts for 55% of the total residential waste stream, demolition 34%, and new construction 11% (Franklin Associates, 1998:ES-3). Figure 1 illustrates the residential and non-residential contributions to the waste stream, Figure 2 the category contributions, Figure 3 the residential marketplace, and Figure 4 the nonresidential sector.

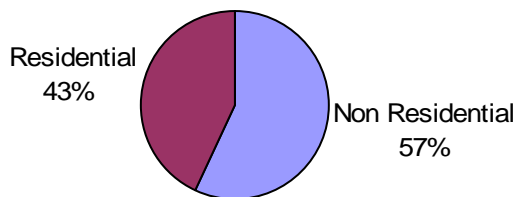


Figure 1. Sources of C&D debris.
Source: Franklin Associates, 1998:ES-2

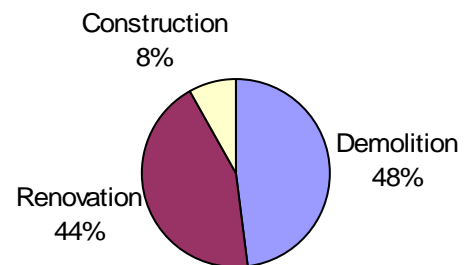


Figure 2. Sources of C&D debris by category.
Source: Franklin Associates, 1998:ES-2

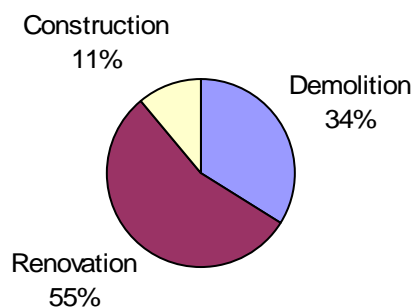


Figure 3. Sources of Residential C&D debris.
Source: Franklin Associates, 1998:ES-3

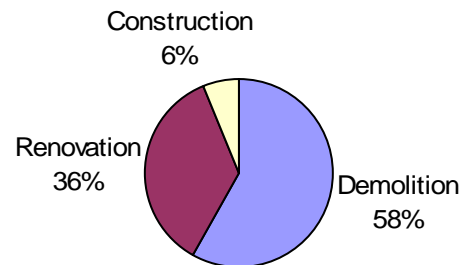


Figure 4. Source of Nonresidential C&D debris. Source: Franklin Associates, 1998:ES

Estimates are that up to 90% of C&D waste is potentially reusable or recyclable, depending on project type and the local market for waste materials (Triangle, 1995:1).

The National Association of Home Builders (NAHB), in a study done for the EPA in 1997, characterizes the waste stream generated by the new construction of a 2,000 square foot home as being constituted of four tons, or 8,000 pounds of debris (NAHB Research Center, 1997). Their characterization of the materials follows in Figure 5, the National Typical House.

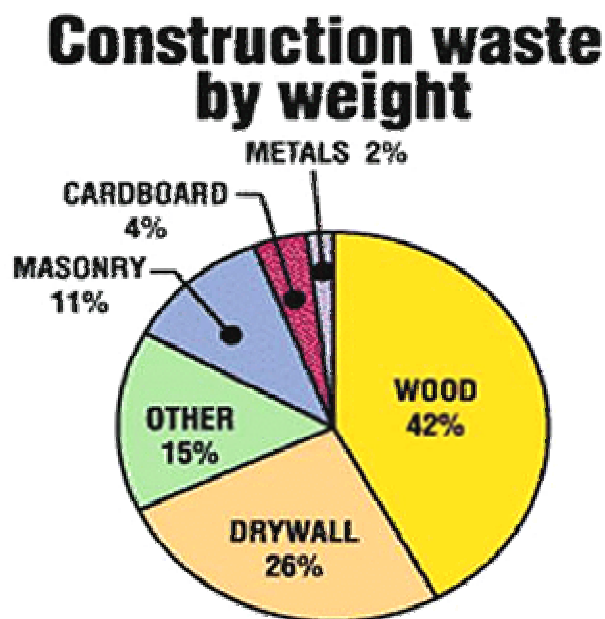


Figure 5. Construction Waste by Weight, NAHB 1997

Waste equals food

There are two main approaches for systematically operating the C&D debris cycle, and an emergent third alternative. The first approach is to transport mixed C&D debris to a central processing facility or materials recovery facility where the debris is sorted. The high value material is high graded out and re-enters the materials supply stream or the material enters a scrap or recycling stream. The low value materials are processed further following their rejection from the material supply stream or the scrap and/or recycling stream and transported for interment into a landfill. The second approach is to separate select materials at the job site and then transport the different materials directly to the markets for those materials (FDEP, 2001). The third alternative is the practice of processing selected materials for end of life use at the job site

The notion of waste equals food is a biological concept. The basic science of ecology knows that waste equals food, and when it does not the natural flow materials becomes imbalanced and ecosystems become compromised. To the extent that systems designed by man mimic this natural law the degree of success enjoyed by the system is much enhanced. Thus, this tactic is relatively new on the national scene and very rare in the H-GAC study area. This systems approach can result in a high degree of waste being turned into food on site and elimination of up to 83% of the typical homes waste stream by weight's contribution to the landfill.

Central processing facility

The centralized facility approach is the most common facility arrangement. Typically, mixed C&D debris is tipped at a central facility, and the materials with a high market value, such as large pieces of sawn lumber, are removed. The remaining mixed C&D materials are then processed using one of two primary methods. The mechanized size reduction method uses a crusher, a dozer, or a compactor. The materials are then passed through a series of screens, magnets, and other separation equipment. The manual labor method relies on human sorters to pick out materials and place them in specific containers. Screens and magnets may also be employed with the human labor method, but the materials are left in their original form rather than crushed so that they can be easily distinguished and sorted (FDEP, 2001:18-19). The most common approach is a blend of the mechanized size reduction and the human sorter methods.

A primary success for a C&D recycling operation hinges on the degree of contamination of the C&D materials by other types of waste such as nails, paint, foil, oil or plastic. Some processing facilities that aggressively handle a mixed waste stream may cause contamination of the C&D materials, thereby limiting their potential to be recycled.

Table 1 summarizes the methods employed by central processing facilities and also includes the estimated volume of material that is rejected from the recycling stream for each method

Table 1. Sorting methods used by C&D central processing facilities. Source: FDEP, 2001:20

Approach	Description	Reject volume
Manual separation only	Waste is tipped. Large identifiable materials with ready markets are removed by hand. The remaining material is land filled.	High (>50%)
Combination manual and mechanical separation (most common approach)	Waste is tipped and screened. Manual labor is used to remove the components on a conveyor belt.	Medium (25-50%)
Heavy mechanical processing and separation	Waste is tipped and processed (often crushed) and sent through a complex train of mechanical equipment for separating the materials.	Low (<25%)

Job site material recovery

The practice of sorting and processing materials at the job site can result in a higher degree of material recovery but is less commonly used in residential C&D practice. To sort C&D materials onsite, contractors need to either arrange for C&D debris haulers to visit the site during the different stages of C&D activity and waste generation or set out different containers for the different waste materials. Some of the factors that have limited this approach are a lack of

experience with job site material recovery, a lack of space for different containers on the job site, and the need for rapid completion of many C&D projects (FDEP, 2001:22).

Various types of equipment are available for C&D processing and recycling, either at a central processing facility or at the job site. Table 2 describes some common types of C&D recycling equipment.

Table 2. Common types of C&D recycling equipment. Source: FDEP, 2001:39

Equipment	Materials processed	Usage
Compactors	Drums, pallets, cranes, bulky waste	Compacts waste with over 65,000 lbs. of force & displaces over 175 cubic yards per hour
Pulverizers	Gypsum, industrial trash, soft metals	Punctured pieces of materials are dropped between rotating high teeth then screened
Loading cranes	Steel, C&D debris, land-clearing debris	Used for the removal of debris in logging operations and construction sites
Separation systems	All C&D debris	Material is fed onto a vibrating screen in which the trommel sorts and discharges waste
Balers-horizontal	Cardboard, metal, paper, plastic	Like separation systems, but designed with side-fed units
Granulators	Plastics, rubber, foam, crates, bins	Materials are broken up into pieces by rotors then reduced into pellets by rollers' teeth
Tub grinders	C&D debris, land-clearing debris	Grinds materials from 120-320 cubic yards per hour from a top feeder with dual auger discharge
Trommels	Yard waste, wood chips, sludge	From a conveyor belt the fed material is screened and dispersed evenly, then outfed and stacked
Hauling trucks	Solid waste, scrap, bulky materials	Hauls solid waste materials up to 44,000 lbs.
Trailers (transfer, roll-off, and walking floor)	Solid waste, scrap, sludge	Hauls solid waste materials up to 80,000 lbs.

On-site material processing

The third approach on-site processing of materials presupposes to take tactics from the two main approaches and deploy the technology to the site and to do what makes sense in terms of processing. In the *On-site Grinding of Residential Construction Debris: the Indiana Grinder Pilot* conducted by the NAHB Research Center in 1999, concluded that 90% of the waste stream is potentially recyclable or reusable on-site.

On-site processing has been evaluated in numerous states and has found to be highly successful in all of the studies conducted regardless of geographic location. The likelihood that this will become the dominant method of processing east of the Mississippi River is very high. The primary element leading to the successful deployment of residential scale on-site materials processing is a portable

residential scale grinder capable of handling wood, shingles, drywall, nails, concrete, cardboard, and brick.

II. C&D waste mitigation and salvage

Numerous waste mitigation strategies exist for C&D waste. Contractor strategies, building code specifications, and a technique called “optimum value engineering” can all help to minimize the C&D waste stream. However, the most important factor is the policy prospective of the political jurisdiction that operates the landfill.

The following list offers examples of strategies that different cities and agencies have employed to mitigate C&D waste, (some of the strategies may have been employed in the commercial industrial marketplace but the concept could be transferred to the residential setting).

- The University of Texas Health Science Center at Houston's goal was to have no materials land filled as it deconstructed a building on a site it sought to build a larger building upon, but found this goal to be impossible. The University with its architect created drawings wrote specifications and developed guidelines, and a more realistic goal was set to recycle/reuse at least 70% of the total building. A joint venture between the construction manager and a deconstruction contractor was formed to support the UTHSCH's new deconstruction policy. The result was 77% of the material was diverted from the landfill. (College Planning and Management, June 2002)
- For the construction of the EPA's Research Triangle Park office in North Carolina, the agency incorporated waste separation and recovery into general contractor specifications. Overall, the project had an 80% recovery rate for C&D debris. “As far as recycling is concerned, [contractors] are generally not used to it, but they are capable of doing it,” said Chris Long, EPA Project Manager (EPA, 2003:5).
- Santa Monica, California's Green Building program includes requirements for C&D waste management, including the following: (1) a requirement to recycle C&D waste is included in construction contracts; (2) the reuse of salvaged building and landscape materials is required; and (3) interior building components are designed for future disassembly, reuse, and recycling (EPA, 2003:6).
- Portland, Oregon's building codes mandate that all construction projects over \$25,000 must recycle materials generated at the job site (EPA, 2003:6).
- In Portland, Oregon and Chicago, Illinois, haulers that charge by the square foot, do not require roll-off containers and recycle more than 50% of the jobsite waste are the normal service that builders can buy. The haulers time their pick-ups to coincide with the different phases of construction, so that the different materials are picked up separately. Such clean-up services have been effective in areas that have high disposal costs and established existing recycling markets for common construction waste materials (Toolbase, 2004:5).
- “Optimum value engineering,” also called “efficient framing,” is an engineering technique from the homebuilding industry that reduces the amount of wood used in the framing process without compromising structural integrity (EPA, 2003).
- King County, Washington, (Seattle), operates the C&D recycling program and has two goals: “First, to assure that job-site material is recycled to the greatest extent possible. And

second, to accelerate the adoption of green building practices, technologies, policies and standards in residential and commercial development.” The program is active in the educational and outreach arena and operates cutting edge web based tools to assist contractors in gaining knowledge and information. Of particular note are: case studies section generated by the contractors themselves, a directory of recycling businesses, and a step by step guide on how to recycle construction and demolition waste. (King County, Green Building Home page, dnr.metrokc.gov/swd/bizprog)

- The City of Los Angeles has formally adopted a 70% diversion goal for the year 2020. To achieve that goal they are actively engaged in the community and in the education and outreach business. One particular innovation which they feel will facilitate reaching their goal is the requirement that all new developments or building expansions must include sufficient space in the building or on the project site to collect and store recyclable materials. This ordinance applies to commercial, multi-family, and residential construction. (City of Los Angeles Solid Resources Citywide Recycling
- The City of San Diego has formally adopted an immediate 50% reduction goal and has implemented selected demolition permit fee, waste disposal fee Waivers as a method to induce businesses to utilize “acceptable recycling facilities for recycling concrete and bricks (City of San Diego Manager’s Report).

The EPA recommends that, when contractor bids are initially solicited, that the contractors submitting a bid also be required to submit a plan for reducing, reusing, or recycling the wastes generated onsite. Contractors may be offered the incentive of allowing them to keep the revenues from recycling and savings from avoided landfill costs due to waste reduction. Although it can be difficult to find recycling or reuse markets for some materials, one resource that contractors can consult is the Construction Materials Recycling Association (CMRA), which is an association of C&D debris generators, haulers, processors, recyclers, and re-manufacturers. The contractor plan should include a discussion of the following items (EPA, 2003:7):

1. Carefully estimate the number of materials that will be needed;
2. Identify markets for recyclable materials; and
3. Establish recycling systems onsite and make sure that both contractors and subcontractors receive instructions on sorting their own waste.

Deconstruction, rather than demolition, can also maximize the salvage of materials for reuse or recycling by disassembling buildings and removing materials in stages. Items such as flooring, siding, windows, doors, bricks, plumbing fixtures, ceiling tiles, and structural components can be salvaged. Apart from increased C&D material salvage, deconstruction often brings benefits such as job creation. Deconstruction requires more time and manual labor than does demolition, and in some areas deconstruction is used to train at-risk youth and welfare-to-work program participants (EPA, 2003).

III. Reuse and recycling options for C&D debris

Wood

Wood waste by almost all account constitutes 40-50% of the volume of the residential new construction waste stream. The most common reuse option for C&D wood is as fuel in industrial boilers or co-generation plants. Most wood used for fuel is chipped prior to transport, although wood that has been treated with such preservatives as copper chromated arsenate (CCA), creosote, or chlorophenol should be removed before the wood is chipped (FDEP, 2001:26). In the case of CCA-treated wood, if it is recycled as fuel, the ash is likely to contain large amounts of heavy metals. Those metals probably are arsenic and chromium. Most likely the metals are present in high enough concentration to render the ash as “hazardous” and require its disposal under the hazardous waste guidelines under the Resource Conservation and Recovery Act (RCRA). Therefore, efforts should focus on the reuse of chemically treated wood. Another alternative is to use the wood as a material in cement. In general, disposal-end practices should include improved sorting of preservative-treated wood at C&D recycling facilities and the institution of proper disposal practices (Solo-Gabriele et. al, 1998).

Wood can also be reduced in volume and down-cycled to make wood products of a lower economic value such as plywood, oriented strand board, and wood I-beams. Conversely, the adhesive content of these engineered wood products materials can limit the eligibility for future recycling. The economics of using wood chip waste for engineered wood products depends upon local wood waste markets (Toolbase, 2004:3).

Building materials such as lumber can frequently be reused in their original form. Clean C&D wood can also be laminated with plastic to make a decking material, although this makes the wood almost impossible to recycle later (Turley, 2002). Wood chips can also be used in compost and animal bedding. Natural woody debris can be ground up and used as horticultural mulch (FDEP, 2001:2).

The diversity of the wood marketplace is such that a reasonably mature underground economy exists wherein the amount of wood waste that ends up in the landfill is considerably lower than it might be otherwise expected. In part, this economy is fueled by municipalities who have created a marketplace by going into the mulch business as an attempt to mitigate the rapid loss in landfill capacity by creating a product from the waste. This “waste equals food” business decision allows many of the contractors to contract with builders for one economic rate per cubic yard based upon tipping fees and to then dispose of the material at a mulching operation at a significantly reduced rate and generating a profit margin in between. For some of the larger operators in the H-GAC area this is how they feed their families.

In summary, wood waste can be used in the following applications:

- An industrial fuel source;
- Mulch;
- Composting operations;
- Animal bedding;
- Landfill cover; and
- Some building products.

Cardboard

Cardboard typically represents 11-30% of the C&D waste stream by volume. Corrugated cardboard is the most common building packaging material and is therefore a key component of the C&D waste stream due to the fact that many building materials are shipped to the site in a pre-fabricated, finished state.

Cardboard is one of the most readily recycled materials in the C&D waste stream as long as it is not wet. The cardboard recycling market is well developed, and it can be to the benefit of builders to recycle the cardboard because it otherwise takes up considerable space in waste containers. Cardboard is typically processed and recycled into new cardboard containers (FDEP, 2001:27).

Gypsum drywall

Gypsum drywall comprises by volume between 8% and 15% of jobsite waste (FDEP, 2001:1). 31.5 billion square feet of gypsum drywall was produced by US manufacturers in 2003. Many landfills are prohibiting gypsum drywall from entering their landfill. Clean gypsum board¹ can be ground up and used in the following applications (Toolbase, 2004:3):

- Applied as a soil amendment;
- Used as a raw ingredient in the manufacture of Portland cement;
- Used for animal bedding;
- Used as a bulking agent in composting; and
- Recycled into new drywall (FDEP, 2001:28).

Wood, cardboard, and gypsum can also be ground on-site and applied to the site before it is seeded or sodded. This practice can keep as much as 65% of jobsite waste from going to the landfill. Most states or localities require evidence that this approach does not harm soil or water quality, so the state and solid waste authorities must be contacted before using this method of disposal (Toolbase, 2004:4).

Asphalt shingles

Asphalt shingles are nearly 60% of the shingle market in the United States. In the H-GAC area, that percentage would have to be higher due to the ubiquitous nature of our building style and penchant for uniformity in our master planned communities behind our gates. Shingles comprise approximately 6% of the C&D waste stream by volume (FDEP, 2001:1). Asphalt shingles can be recycled into new shingles, crushed and used as an aggregate in the manufacture of hot mix asphalt, or as a primary material for rural roads (FDEP, 2001). Asphalt shingles also can be successfully ground on-site and utilized as base material for concrete flatwork such as driveways and sidewalks.

¹ Clean gypsum board is free of wood, metal, and plastic, is not asphalt impregnated, and is not coated with glass fiber, vinyl, decorative paper, or any other finish (Design Coalition, 2004).

Bricks

Bricks represent a material in the H-GAC region that is widely deployed and which is highly desirable in the diverted waste stream. The marketplace for bricks is strong because it is composed of two elements. The first is the aggregate business which utilizes bricks as a source of crushed material to create fill and/or base of high quality. The second market in our area is the resale of bricks as an architectural element. The huge number of homes that are built in the H-GAC area each year fuels an underground economy that feeds upon these materials to do small jobs throughout the area. Nationally, this is less of an issue as the residential construction market is not as focused as we are in the H-GAC area on a brick veneer façade.

Concrete

Concrete is one of the most recycled materials in the United States and the world. The primary market for recycled concrete is as a base product for buildings and roads. Crushed concrete and brick can also be used as the primary surface material on rural roads and driveways, in drainage applications, and as borrow pit fill (FDEP, 2001).

Local markets for recycled concrete depend on the presence of local construction and road building markets (Turley, 2002). Markets for recycled concrete also depend on the local availability of such substitutes as lime rock (FDEP, 2001:24).

Metal

Metal is present in small amounts in residential C&D projects. What metal there is comes in the form of wiring, siding, fasteners, and roof flashing. Rarely is high value metal landfilled. There is an effective market based system wherein copper and aluminum are routinely recycled by the tradesperson(s) performing the work or other tradespersons on the jobsite. This is entirely consistent with the underground marketplace for untreated wood products mentioned earlier. When low value metal is present in sufficient amounts, it can be readily recycled in the scrap metal market.

Screened materials

Other recovered materials typically consist of material left over from screening mixed C&D at a processing facility. The screened material typically consists of mostly dirt but can also contain small fragments of wood, rock, paper, drywall, and plastic. One use for this material is for construction fill (instead of soil) for roads, buildings and landfill construction projects. Another use for screened material is as daily cover for landfills. When large amounts of gypsum are present, however, the hydrogen sulfide content of the landfill gas can increase, creating an odor nuisance for neighborhoods located close to the landfill (FDEP, 2001:29).

Miscellaneous

Habitat for Humanity has a number of RE-store locations across the country, including several in the H-GAC area. The RE-store stores serve as both non-profit building materials recycling centers

and discount home improvement centers, providing local markets for used C&D materials and salvaged parts. There is also a southern Montgomery County RE-Store in Conroe. A variety of materials can be purchased or donated at the store (RE-Store, 2004).

Additionally there are a number of private sector second hand and/or architectural building supplies stores that can and do frequently take materials from the C&D cycle and provide a method of redeployment. The H-GAC area also has Historic Houston, a not-for-profit who does the ultimate recycling by accepting a limited number annually of whole houses for redeployment.

IV. C&D debris regulations

Federal regulations

The Resource Conservation and Recovery Act (RCRA) is the primary federal law governing solid waste. Most C&D waste is considered to be solid waste and is regulated under RCRA. The EPA does not generally single out C&D waste for any special regulatory treatment. An exception does exist when C&D waste contains hazardous materials such as lead-based paint, asbestos, or elements such as lead, mercury, cadmium, pcb's and arsenic. In hazardous waste cases, RCRA regulations specify particular disposal methods (Clark et. al., 2004).

Legislation across the United States

Most C&D waste is regulated at the state level, and the requirements for C&D debris disposal facilities vary widely from state to state. Researchers from the University of Florida and the University of Michigan conducted a survey of the fifty states and confirmed, not unsurprisingly, that C&D waste regulations vary from state to state. Interestingly enough, about half (23) of the states have specific C&D regulations while in the remaining states (27), C&D debris is regulated under the requirements for municipal solid waste (MSW) landfills, non-MSW landfills, general inert debris landfills, or general solid waste facilities (Clark, et. al., 2004:8). Of the 50 states, 27 permit the disposal of general C&D waste into unlined landfills; the remaining 23 states have varying requirements for liner systems (Clark, et. al., 2004:8). Groundwater monitoring for landfills is required by 27 states (Clark, et. al., 2004:12).

Because of growing awareness that C&D debris can contain hazardous materials such as lead-based paint, asbestos, or wood coated with CCA (copper chromated arsenate), some states are in the process of revising their C&D debris regulations. These states include California, Colorado, Kansas, Massachusetts, North Carolina, Ohio, South Carolina, and Washington. In the State of Massachusetts, concrete, asphalt, brick, wood, and cardboard were banned from landfills at the end of 2003 although implementation has been delayed (Clark, et. al., 2004:13). California is developing regulations for recycling facilities that would require mixed C&D debris recycling facilities that accept more than 175 tons per day (recycling at least 60% of that) in order to obtain a solid waste permit (Clark, et. al., 2004:14). Increased regulation can cause C&D tipping fees to rise, which can result in increased C&D recycling (Clark, et. al., 2004:13-14).

There are a number of examples of policies that states and cities have instituted to encourage C&D recycling. In San Jose, California, demolition contractors must pay a deposit based on the square footage of their project in order to receive a city building permit. The deposit is refunded if the contractor can demonstrate that the C&D waste was taken to a city-certified recovery facility (FDEP, 2000).

In Portland, Oregon the city requires job-site recycling of rubble (concrete/asphalt), land-clearing debris, corrugated cardboard, metals and wood on all construction and demolition projects with a permit value exceeding \$50,000. This is accomplished by requiring a complete site plan prior to permit issuance.

Another example is in Florida, where state solid waste legislation established recycling goals for counties, and a certain amount of C&D waste was allowed to count toward those goals. A cap was placed on the amount of C&D waste that could be counted toward that recycling goal, so that counties would have to recycle other types of waste as well (FDEP, 2000).

In October 2002, Orange County, North Carolina, enacted an ordinance regulating recyclable materials, including C&D waste. The ordinance requires the recycling of specific materials and was coupled with plans for an additional C&D landfill. In addition, people requesting building permits are now also required to apply for a "Recyclable Material Permit" that requires the permit holder to state what types of waste they anticipate generating and how they will manage that C&D waste. This ordinance, while making specific demands on the business community, won broad-based support because of the new C&D landfill commitment. It should be noted that the ordinance has resulted in decreased tipping fee revenues. The reduced revenue has been partially offset by sales of recyclable material, for the Solid Waste Management Department, which operates the Orange County landfill and the county's recycling programs. The important impact on the C&D waste stream was the significant reduction in waste and the increase in the recycling of material, as Table 3 shows (Ghirardelli, 2004).

Table 3: Construction Waste Disposed and Recycled in Orange County, NC 2001-02 vs. 2002-03.
Source: Ghirardelli, 2003

	FY 2001 / 2002	FY 2002 / 2003
Disposed (at solid waste facility)	27,729 tons	19,085 tons
Disposed (elsewhere)	7,352 tons	7,035 tons
Subtotal	35,081 tons	26,120 tons (26% reduction)
Recycled (at solid waste facility)	1,099 tons	3,311 tons
Recycled (elsewhere)	0 tons	6,653 tons
Subtotal	1,099 tons	9,964 tons (9-fold increase)

A growing threat to C&D waste recycling is the increase in franchise agreements between demolition contractors and municipalities around the country. These contracts require all solid waste (even that which can be recycled) within a jurisdiction to be sent to one place designated by the local government or hauler, thereby limiting the flow of C&D waste and other debris to waste recyclers. Because even highly recyclable C&D waste such as concrete is designated as solid waste, these franchise demolition contractors are allowed to dump these materials in local landfills.

Complicating the situation is the political reality that demolition companies pay a stipend to the local government in order to obtain the franchise agreement. This stipend often serves as an important source of revenue to municipalities' solid waste department (Turley, 2004). In Ohio, a state law prohibits governments from including C&D waste in solid waste franchise agreements (FDEP, 2000).

Best practices

The Florida Department of Environmental Protection (FDEP) offers a list of C&D regulatory best practices, an excerpt of which is included below. The list provides a summary of the different actions that entities at every governmental level can take to encourage C&D recycling (FDEP, 2001:3-4).

Local government can do the following:

- Fund public education and outreach programs designed to educate the public and to create small business opportunities for the municipality;
- Implement a mandatory recycling policy of selected materials prior to permit issuance when the dollar value exceeds a specific threshold i.e. \$50,000;
- Implement curbside collection for selected C&D materials;
- Decriminalize the salvaging of building materials from demolition sites;
- Implement Green Building programs;
- Provide tax incentives to businesses that recycle;
- Maintain an open market for C&D debris collection;
- Issue permits to roll-off box haulers but not to franchises;
- Require non-exclusive commercial franchises, and
- Rebate a portion of the franchise fee if recycling occurs.

State governments can do the following:

- Fund a public education and outreach effort to educate the public on C&D issues and opportunities;
- Enact a Green Building bill for all state and local government building and renovation projects with a high recycling of C&D materials goals;
- Enact a "Recyclable Construction and Demolition Debris" (RCDM) bill;
- Prohibit solid waste franchises from covering C&D debris with clay based soil and instead require the covering be quality compost (Clay coverings contained in Ohio's RCDM legislation);
- Make a distinction between material recovery facilities and non-recycling processing facilities;
- Require C&D debris to be processed before disposal (a Massachusetts law);
- Require liners for C&D debris disposal facilities;
- Provide sales tax exemptions for recycling equipment i.e. on-site grinding equipment;
- Provide sales tax exemptions for recycled construction materials;
- Provide grants to local governments to improve C&D debris recycling, and
- Provide low-interest loans to recycling businesses.

Legislation in Texas

There are 45 C&D landfills in Texas (Kaufman et. al., 2004). Of these, 38 are permitted as Type IV facilities, which accept only brush, C&D debris, and other waste that will not putrefy (TCEQ, 2003). However, non-hazardous solid waste, including most C&D waste, can be sent to several types of landfills in addition to the Type IV variety (Clark, et. al., 2004:48).

Type IV facilities are required to have a liner composed of either (1) at least 1.22 m (4 ft) of in-situ soil with permeability no greater than 1×10^{-7} cm/sec between the deposited waste and groundwater or (2) at least 91 cm (3 ft) of compacted clay between the deposited waste and groundwater. Groundwater monitoring is also required except at arid facilities (Clark, et. al., 2004:48).

A fundamental Texas problem is the manner of enforcement for non-licensed dumpsites. The TCEQ is charged with the enforcement for all regulated facilities regardless of type and do so with dedication and professionalism. Non-licensed dump sites are a legal issue left to municipalities and counties for enforcement. The consequence of this gap in oversight and accountability is so great as to create an economic incentive to operate outside the law and create public nuisances and greater public risk.. It appears that there is an opportunity for better oversight and control of non-licensed dumpsites. The legislature should fulfill its responsibility to the people of Texas and pass enabling legislation to empower the TCEQ to enforce the law and remove the public from risk.

Local practices in Texas

C&D waste comprises about 22% (equaling 6,424,228 tons) of the total Municipal Solid Waste (MSW) stream in the State of Texas (TCEQ, 2003). In the 13 county H-GAC region in the year 2000, 38% of the waste disposed of in MSW landfills was C&D waste. The 13 county area has 11 active Type IV landfills for C&D waste (H-GAC, 2002). We are fortunate to have a lot of land to dedicate to solid waste. As long as the facility is “not in my back yard” (NIMBY) we will most likely not have a shortage of landfill space. Due to this, it remains very inexpensive to own and operate a MSW facility in the State of Texas. It remains true for Texas that a considerable amount of our land is not now being utilized at its highest and best use. Until the time comes when our population density reaches a greater ratio than that which we now have, it is entirely practical in many parts of our state for industry and municipalities to utilize land as a site for solid waste.

Only when land costs are driven completely out of the reach of the general public by the combination of the relentless march of human procreation and the endorsement of sprawl as the method of economic development will we act. Then and only then, will the cost of the waste stream cause any significant alteration in the behavior of the citizens and number of landfills and the resultant acreage devoted to waste handling be addressed.

Further, since there is no current vibrant market for C&D waste products and there are no policy inducements for State and local government to consider C&D products in the procurement cycle it is highly suspect that a market condition is going to dramatically shift the current paradigm. It is highly unlikely that the total amount of landfill capacity will be sufficient to meet the demand placed upon them by a booming population for an extended period of time. Therefore, political action will be necessary in a more rapid timeframe than some of the studies might suggest.

Table 4. Waste Fees for HGAC counties

County	Landfill	Cost per cubic Yard	Permit Number
Austin	No Landfill	\$12.50-\$18.50	
Brazoria	Brazoria County Landfill	\$ 7.00	2235
	Dixie Farm Road Landfill	\$6.00	1708
	Seabreeze Environmental Landfill	\$ 7.25 (lower if set up an account)	1539
Chambers	County Landfill	\$ 0.03 Cents per pound	1502
	Baytown Landfill	\$ 7.50	1535
Colorado	Clean Harbor/Altair Landfill	\$ 9.88	203
Fort Bend	Sprint Fort Bend County Landfill	\$ 6.50	1396
	Longpoint Landfill	\$ 5.25 for more than 18 cy, \$7.25 for less than	2270
	Blue Ridge Landfill	\$ 10.10	1505
Galveston	North County landfill	\$ 6.10	1849
	Galveston County Landfill	\$ 10.10	1149
Harris	Atascocita	\$ 6.05-\$10.55	1307
	McCarty Road	\$ 10.55	261
	CASCO Landfill	\$ 7.00	1403
	Cougar Landfill	\$ 6.25 (\$3.00 environmental fee)	1921
	Greenbelt Landfill	\$ 6.05	1483
	Fairbanks Landfill	\$ 7.00	1565
	Ralston Road Landfill	\$ 5.80	2240
	Greenhouse Road Landfill	\$ 7.00 (\$25.00 minimum)	1599
	Liberty	No local landfill	
Matagorda	No local landfill		
	Matagorda County Transfer Station	\$ 40.00 per ton	40028
Montgomery	Security Landfill	\$ 7.00	1752
Walker	No local landfill		
Waller	No local landfill	\$60.00 per ton	
Wharton	No local landfill	\$10.00-\$30.00	

**Figure 6. Harris County landfill rates**

The public is generally unaware of the extent of the volume of C&D waste. Wood is by far the largest component of waste material generated at residential C&D sites in the H-GAC region. C&D waste reduction in H-GAC is viewed as an “economics only” issue by the developers and the builders. There are literally thousands of instances of “guys with \$900 dump trucks” who are more than willing to haul C&D waste for very little compensation absolving the builder of any responsibility. This practice has led to a very active underground wood recycling program that is more effective than one would first think. Driven by extraordinarily fierce competition to clean up the production builder’s job sites before Saturday morning, these creative, adaptable entrepreneurs are recycling massive amounts of wood in an underground economy designed to feed their families.

At commercial/institutional demolition sites, concrete is generally the top waste material generated. Southern Crushed Concrete is the primary concrete recycler in the H-GAC area and operates eight recycling yards in the region. Cherry Crushed Concrete also operates two processing yards and a mobile processing unit (H-GAC, 2002).

Barriers

Abundance of Inexpensive Land

One reason as to why C&D waste is handled in the traditional landfilling method in the state of Texas is the relative abundance of cheap land. When compared to a state such as Vermont, Texas has plenty of open land in which to dispose of its solid waste. While tipping fees in the Houston area average \$5- \$12 per cubic yard, Vermont’s fees range from \$60-\$80². The cost then of land filling waste is relatively inexpensive, providing little incentive for builders to seek alternative waste management methods.

Tradition

As mentioned above, the traditional way of handling C&D waste is to haul it off to a landfill. As the old adage goes, “if it’s not broke, don’t fix it”. Cost of landfilling waste in the past years has not risen dramatically, giving no reason for builders to change their methods of dealing with C&D waste. As long as their traditional methods of business continue to function in a cost effective manner, there will be no catalyst to change.

Price and Cost Confusion

There is a difference between price and cost of land filling that is not easily seen in a generic cost statement. The inexpensive price of today’s landfilling fees does not take into account the opportunity cost of land, the loss of materials for recyclers or environmental damages. While builders gain in lower costs, recyclers lose out due to lack of material.

²“Northeast Tipping Fees” Chris Campman Manager Solid Waste Gannett Fleming, Inc., Federation of New York Solid Waste Associations, Spring 2001 Conference May 6-9, 2001 Bolton Landing: New York, <http://www.nvfederation.org/PDF/NETippingfee.pdf>, pg3.

Lowered quality of our water sources and the cost it will take to make this water suitable for drinking in the future is an example of this environmental damage. Environmental damage also has a human factor. Included is also the cost of the loss of productivity of workers who become ill because of polluted water sources. Bottom line, our resources are exhaustible and landfills deteriorate the quality of the land that we might not need for resources today, but will need in the not so distant future.

Uneducated Tradespeople and Builders

Due to the differences of recycling versus landfilling, there seems to be a perceived complexity in recycling. In reality, recycling is no more difficult than landfilling; it just requires a process that is unfamiliar. The industry sees this change as perceived hassles and is wary of approaching it. There is an overall understanding of the concept of recycling but difficulties arise when the concept is translated into action. There is a large amount of misinformation expressed due to perceived lack of public and private education.

Lack of communication with political representatives

Our elected officials are not mind readers and so can only represent legislation they are aware is supported and popular amongst their constituent base. All constituents, from trades and builders to the general public, need to be educated on the topic of C&D waste. Only when an educated public communicates with elected officials to press the issue, will legislation be developed to address the C&D waste issue. Health and safety of their constituents is a primary concern of elected officials. When educated constituents press an issue from a health and safety viewpoint, elected officials respond. Just as a company pursues profitable endeavors to please their stockholders, elected officials pursue legislation that will please their constituents.

Big powerful lobbies

Coupled with an uninformed public is lobbying from the interested waste stream management industry. The current waste stream management industry's profitability would be affected by disruptive technology. The 'status quo' enables companies to run their business in a cost effective, profitable manner and a change in operations could affect this profit. An educated public could convince elected officials to change policy, enabling current waste management companies to consider change and disruptive technologies without reducing profits.

Few positive public models

The reason for few positive public models ties into the lack of communication with political representatives. If there is no pressure from the public to make a change, there will be no reason to spend time and money pursuing such alternatives. The recent razing of more than 100 single family houses by the City of Houston in which there was no recycling attempted is a negative example, another is the fact that limited opportunities exist in state and local purchasing procedures for the reuse of C&D recycled materials.

Fewer Positive Private Models

Uncharacteristically protective builders and contractors in the H-GAC area have seen no compelling reason to recycle and there is no regulatory or market based demand thus, until the time that either of these events takes place there is little or no likelihood that large scale change can take place.

Lexicon of confusion

The stock of terms used by professionals focused on sustainability does not always lend itself to understanding by those unfamiliar with the field. Even the definition of sustainability differs within the field creating further confusion and frustration. This creates an unintentional barrier for those who would like to pursue such objectives and are approaching the concepts for the first time.

C & D Waste Stream Audit

Overview

HARC contracted with H-GAC to conduct a residential waste study. Included in the study was a requirement to perform waste stream audits of possibly three sites. The audit was difficult for HARC to initiate due to the extreme reluctance of production builders to allow HARC access to their cost structures and waste streams. This reluctance was so great that the project did not initiate until more than five months had expired and HARC never did secure a production builder partner. This was most unfortunate and is a situation that should be rectified in the future by doing a similar piece of work specifically with a production builder in order to compare, contrast, and draw knowledge from this study.

HARC secured two sites. Tom Cox Builders, Inc., a thirty-five year old custom home building company in The Woodlands, agreed to allow HARC to analyze the waste stream for one residence.



Figure 7. Benefactor



Figure 8. Site sign

H-GAC staff agreed to the custom builder selection. Six weeks into the relationship we approached Mr. Cox with the possibility of doing something beyond simple characterization in a second house site and he agreed. Thus, two large custom houses are the subjects of this audit. In the instance of the first house, 190 North Tranquil Path, the residence was a 7,929 square foot one story house. At this building site, HARC performed an audit of the waste stream. The second house was located at 234 Angel Leaf and was a 7,789 square foot two-story house with a swimming pool. At this second site HARC went a step beyond auditing the waste stream to incorporate and evaluate the potential on-site grinding technique for waste management. The on-site building crews and the construction superintendent were consulted and a methodology was agreed upon. The first decision on both sites was to secure the areas where the roll off containers, holding the landfill destined material, would be located.



Figure 9.
190 North Tranquil Path



Figure 10.
Crushed concrete



Figure 11.
A 30 yd roll off container

HOUSE ONE C&D WASTE STREAM AUDIT

Protocol and partners

The audit for the first house began on May 26, 2004 with the setting of the two 30 cubic yard roll off containers on the site by BFI, Inc. BFI, Inc. was selected after a competitive process was conducted to secure the best pricing and agreement with the conditions of the audit. After a comparison of waste services, BFI was chosen by HARC as the waste hauler for the construction waste audits in Grogan's Point area for two reasons: 1) a pricing structure that was more favorable to the expected audit process and 2) the option to recycle wood and cardboard. HARC agreed with BFI that all dumpsters would be weighed for the HARC audits. The intended procedure for a load of material was that a HARC representative would meet the driver at the construction site and follow the truck to a Flying J service station. The truck would then be weighed. The HARC representative would then follow the truck to the recycler and observe the lumber being dumped. The truck would return to the Flying J and weigh the container and the truck empty and a weigh ticket would be provided to document the actual weight of the containerized materials.

HARC employed an intern to assist in the auditing and characterization effort. HARC trained the intern in the field methods HARC wanted to employ, and familiarized the intern with the C&D estimation process. HARC made a digital camera available to the project. HARC instructed the intern to photographically document the project virtually at will. A manual logging system to identify material and volumes was employed as the logical control mechanism for the first container that had been identified for clean sawn wood. The principal investigator and the intern routinely visited the site to inspect the logging process and to estimate the waste materials and the related volumes. The second container was reserved for additional wood materials but there was a clear recognition that the material would not be wholly sawn dimensional lumber as the first container but would contain some engineered wood.

Individual scale recycling receptacles were purchased and placed on site for aluminum, plastic, glass and trash with hopes to mitigate trash entering the study at inappropriate times. The construction superintendent allowed HARC to speak to the onsite crews and explain the project objectives and the role that they could play in the project. The intern visited the site everyday, and if necessary segregated waste and hauled trash.



Figure 12. Individual receptacles



Figure 13. First wood, forms package

June 2004 was the wettest June on record for the state of Texas, according to NOAA (<http://www.noaanews.noaa.gov/stories2004/s2265.htm>) with 20 days of rain recorded at Bush Intercontinental Airport (<http://www.srh.noaa.gov/hgx/climate/iah/jun04iah.txt>). The large amounts of rain and frequent storms during June significantly slowed the pace of construction, and correspondingly caused large delays in the audit.



Figure 14. Wettest June



Figure 15. Dumpster diving

Also, to make the site ready, the builder had to purchase and apply crushed concrete to the site to facilitate access. Work proceeded slowly and framing was not complete until July 17, 2004. The intern spent a fair amount of time “dumpster-diving”, packing, stacking and cleaning out the first 30 yard roll off container. Our plan for the audit contained two components. The first step was to estimate the volume and weight of the waste material using the EPA’s fairly simple estimation tool and secondly, to run the C&D waste containers over a set of scales (full and empty) to obtain the actual weights of the material. This would afford us an opportunity to compare the predicted weights using the EPA methodology versus the actual. This would help us determine whether it made any sense to employ the tool in the handbook and training, which was required in the contract.

The planned methodology worked for the first container and all other containers in this audit but failed for the second container. This failure was a huge disappointment and a complication that was not anticipated. The plan failed when the contractor's dispatcher failed to instruct the driver of the procedure to drive the truck and container over the scales. The dispatcher also had failed to tell the driver that the haul was clean wood and subsequently all of the material was land filled instead of recycled. This event was witnessed by the intern who raced after the driver and the container, through toll booths and to the gates of the landfill only to be just a little too far behind the driver for the waste contractor to ever have know that he was being pursued. Subsequently, the dispatcher was fired for this and other issues.

Methodology

HARC made use of a calculator frequently cited by the EPA, adapted from a NAHB research project. The calculator converts the volume of materials into pounds. Understanding the waste stream requires us to use consistent units. Since drywall is far denser than cardboard, a dumpster full of drywall will weigh far more than a dumpster of cardboard, hence the need of conversion factors. The following table presents the conversion factors employed by HARC in this process whenever actual weights were not possible to obtain.

Table 5. Conversion factors used by HARC

Material	Pounds per Cubic Yard	Cubic Yards per Pound
Solid Sawn Wood	267	0.004
Engineered Wood	280	0.004
Drywall	400	0.003
Cardboard	30	0.033
Metals	150	0.007
Asphalt Shingles	400	0.007
Masonry	1000	0.001
Paints, Caulks, etc.	167	0.006
Mixed Wastes	95	0.010

HARC attempted to carefully estimate the quantity of wood emptied and stacked into the first container. The values employed were 267 pounds per cubic yard for solid sawn wood and 280 pounds for engineered wood products as shown in the table above. This is one of the most problematic areas in the study as there is great variability in weights as a result of the packing density of the containers, most often based upon the sizes and shapes of the waste itself. In the instance of the first and second containers of Waste Stream Audit One, the packing was particularly tight because HARC hand sorted and packed the containers. Thus, the actual weight for the first container was much higher than the calculator's predicted weight. The variance is a result of an assumed degree of unfilled volume by the calculator.

This presumption becomes more problematic later in the audit. In later hauls, the nature of the density and/or the increase in the amount of loose wood or other materials contributed to the container's volume being utilized but the weight is significantly less than those first two hauls. Thus, the volume for the container remains the same at 30 cubic yards but the weight of the later haul containers is reduced greatly and more nearly matches the expected weights from the EPA calculator.

Audit Process and Findings

Haul One

Haul Number One was conducted on July 12, 2004. The assumption of a field estimated 27.9 cubic yards of material filling a 30 cubic yard container was utilized. Field estimation of volume was based on observance and the manual log which construction workers were asked to execute as they filled the containers.

Utilizing the EPA calculator, this haul consisted of: (1) forms from the slab, solid sawn wood equaling 4,272 pounds (16 cu yards * 267 lbs/cu yd) and (2) framing timber, solid sawn wood equaling 3,177 pounds (11.9 cu yards * 267 lbs/cu yd) for a total predicted weight of 7,449 pounds.

When the truck and container passed over the scales, the weigh ticket resulted in 11,100 actual pounds. The variance of actual to predicted weights was 3,651 pounds. When the container was reset on the site, HARC reserved the container for the upcoming shingle phase of the project.

House One Landfill Waste

Date	Haul	Weight(lbs)	Details
7/12/2004	1	11,100	Frame



Figure 16. End cuts of lumber



Figure 17 and 18. Solid sawn wood content from haul one

Haul Two

Haul Number Two, conducted on August 3, 2004, consisted of: (1) rafters, solid sawn wood equaling 2,376 pounds (8.9 cu yards * 267 lbs/cu yd) and (2) roofing sheathing, an engineered wood product, equaling 5,068 pounds (18.1 cu yards * 280 lbs/cu yd).

House One Landfill Waste

Date	Haul	Weight(lbs)	Details
8/3/2004	2	7,444	Rafters& sheathing

Again utilizing the EPA calculator HARC calculated a predicted weight of 7,444 pounds with a field measured 27.0 cubic yards of material filling a 30 cubic yard container. Haul Two turned into a runaway 30 yard roll off container. As a result, no actual weight is available and the clean wood was taken to a landfill. When the container was returned to the site, it was earmarked for its next load to be the remaining wood, cardboard and mixed use container.



Figure 19. Solid sawn wood



Figures 20-21. Engineered wood including TechShield

Haul Three

During the month of August the structure was being enclosed (“dried in”), meaning the sheathing and the shingles were being installed. Interestingly enough, the EPA calculator based upon the NAHB study did not include shingles’ calculation. Therefore, HARC conducted an extensive web search and concluded that the appropriate value for use in this H-GAC study, while being consistent with the EPA calculator was 400 pounds per cubic yard. As Haul Three was about to take place, the calculator’s value for commingled or mixed waste became an issue as a frequent problem that confronts builders appeared in our study. The neighbors by this juncture decided the containers were for public use and began to dump their trash into them with impunity. Since the container was primarily full of shingles, HARC chose the mixed waste calculator value of 95 pounds per cubic yard because the commingled waste included a significant amount of the very light polystyrene sheathing.

Haul Three was conducted on September 10, 2004. Haul Three consisted of: (1) shingles equaling 10,800 pounds (27 cubic yards * 400 lbs/cu yd), and (2) mixed wastes equaling 266 pounds (2.8 cubic yards * 95 lbs/cu yd) for a total predicted weight of 11,066 pounds with a field measured 29.8 cubic yards of material filling a 30 cubic yard container.

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
9/10/2004	3	12,080	Shingles & some commingled

The weigh ticket resulted in 12,080 actual pounds. The variance of actual versus predicated weight was 1,014 pounds. When the container was returned it was earmarked to contain drywall debris next.



Figures 22-24. Asphalt shingles from Haul Three

Haul Four

Haul Four was also conducted on September 10, 2004. Haul Four consisted of: (1) solid sawn wood equaling 2,136 pounds (8 cubic yards* 267 lbs/cu yd), (2) engineered wood equaling 560 pounds (2 cubic yards* 280 lbs cu yd) and (3) cardboard (19 cubic yards* 30 lbs/cu yd) equaling 570 pounds for a total predicted weight of 3,266 pounds with a field estimated 29 cubic yards of material filling a 30 cubic yard container.



Figures 25-27. Solid sawn wood and cardboard from Haul Four

The weigh ticket for this 30 cubic yard haul was 3,040 pounds. The variance of actual versus predicated was – 226 pounds. Upon return, the container was identified as the bricks and mortar container.



Figures 28-30. More wood and cardboard from Haul Four

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
9/10/2004	4	3,040	Cabinets, cardboard, some wood

Haul Five

Progress on the house was moving along rather quickly during the September 2004 timeframe. The masons had arrived and began the process of bricking the home, and the drywall (sheetrock) crew arrived to begin sheet rocking the interior space. Both of these processes generate an enormous amount of waste compared to early processes and corresponding time frames.

Haul Five took place on September 21, 2004 and consisted primarily of brick, and mortar. Utilizing the EPA calculator HARC estimated the container consisted of: (1) 9,000 pounds of bricks and mortar (9* 1000 lbs/cu yd) and (2) 270 pounds of cardboard (9* 30 lbs/cu yd.) for a total estimated weight of 9,270 pounds. The weigh ticket for this container was 9,460 pounds. The

variance of actual versus predicted weight was 190 pounds. When the container was returned it was again designated as a brick and mortar receptacle for the next haul.



Figure 31. Bricks on-site



Figure 32. Bunks of Brick

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
9/21/2004	5	9,460	Brick, Mortar, Dirt

Haul Six

Haul Six took place on October 4, 2004. Haul Six was a drywall only container. Again, making use of the tally sheet and the EPA calculator, HARC estimated the container to be composed primarily of drywall in the amount of 28 cubic yards of material, with an estimated weight of 11,200 pounds (28* 400 lbs/cu yd). When the container passed the scales it weighed in at 12,820 pounds for a variance of 1,620 pounds.

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
10/4/2004	6	12,820	Drywall



Figures 33 and 34. Drywall (sheetrock) from Haul Six

Haul Seven

HARC did not attempt to estimate the weight for Haul Seven. We knew from the foreman that the waste from the “lot clearing” was coming and there was no reliable method to do the calculation for what was anticipated. We felt this was a reasonable decision considering what took place as depicted from the pictures below in Figures 35-37.

Haul Seven took place October 28, 2004. The contents of the container consisted of the second phase of the lot clearing and the final cleanup of the wood waste from the site. The container also held all wooden palettes and the wood (trim) from the interior spaces. This container had been intended to be a wood waste container. Haul Seven was scaled at 8,940 pounds and is pictured below.

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
10/26/2004	7	8,940	Brush, pallettes



Figures 35-37. Contents of Haul Seven: lot clearing, pallettes, and a tire!

Haul Eight

Haul Eight took place on December 13, 2004. The container contents were primarily of concrete, bricks, mortar and cardboard. HARC did estimate this container. The estimate was a very full 30 cubic yards consisting of: (1) concrete and bricks equaling 12,000 pounds (12 cubic yards* 1,000 lbs/cu yd) and (2) cardboard equaling 510 pounds (17 cubic yards* 30 lbs/cu yd) for a total predicted weight of 12,510 lbs with a field estimated 30 cubic yards of material. The haul scaled out at 13,720 pounds, by far the heaviest of any haul made in the project. Apparently some of the flat work was not acceptable and discarding it was the easiest way to handle the issue (see figures below).

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
12/13/2004	8	13,720	Concrete& Bricks



Figure 38. The unacceptable flatwork



Figure 39. Mixed contents of Haul Eight



Figure 40. Cardboard en mass

Haul Nine

Haul Nine took place on January 5, 2005. Utilizing the EPA calculator, this haul consisted of: (1) site cleared wood 3,738 pounds (14 cu yards * 267 lbs/cu yd) and (2) interior trim wood, solid sawn wood equaling 2,403 pounds (9 cu yards * 267 lbs/cu yd) and (3) cardboard equaling 210 pounds (7 cu yards * 30 lbs/cu yd) for a total predicted weight of 6,351 pounds. The container was actually scaled at 6,820 pounds. The container held the final site clearing debris, the interior trim package waste and all remaining discarded cardboard on the site.

House One Landfill Waste

Date	Haul	Weight (lbs)	Details
1/5/2005	9	6,820	Trim, brush, cardboard



Figure 41. Haul Nine



Figure 42. Interior trim wood, solid sawn wood

Summary of House One

In total, the house generated 85,242 pounds of C&D waste. According to the national average based on NABH studies, a typical 2,000 square foot house generates 8,000 pounds of waste. This is verified in previous studies and confirmed in the Franklin report. This house was 7,929 square feet. If we were to extrapolate the 2,000 square feet to 8,000 square feet one would expect something on the order of 32,000 pounds of C&D waste.

House One Total Landfill Waste

Date	Hauls	Weight(lbs)	Yards
7/2004-1/2005	9	85,242	247.7

This study did not even come close with its 85,242 pound total. Our differential from the expected result is 53,242 pounds. That is a 266.4% variance from the expected result. The pie charts in Figures 43 and 44 below depict the ratios of waste make up for the study house and the national typical house. One of the striking differences in the two charts is the 236% increase in the brick component of the C&D waste stream. This is significant inasmuch as, according to the EPA calculator, bricks weigh an estimated 1,000 pounds per cubic yard. This is an indicator of the primary cause in the variance. The fact that H-GAC area's modern hot and humid houses typically are built with a significant increase in the volume of enclosed space leads to this surprisingly large increase in the amount of material required to create the envelope and the resultant interior components such as drywall. This is simply a function of geometry that builders are forced to deal with in this marketplace. To illustrate this point is the following example. If a wall section is 10 feet high in a modern hot and humid climatic zone house and the comparison circa 1996 national typical is an 8 foot wall section, then 25% more material is required to cover the same square footage of space.

The fact that there is a variance should not come as any surprise due to the response to climatic differences in the nation's typical house versus the typical house in the hot and humid area. The surprise comes in the enormity of the variance. It is curious that the shift in materials (-28%) away from wood and drywall is fully accounted for in the increase in the percentage of bricks and masonry used. We have some opinions about the possible causes of the variance and suggest them in the following observations section.

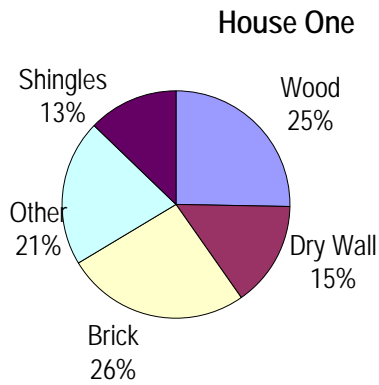


Figure 43. C&D waste-stream makeup

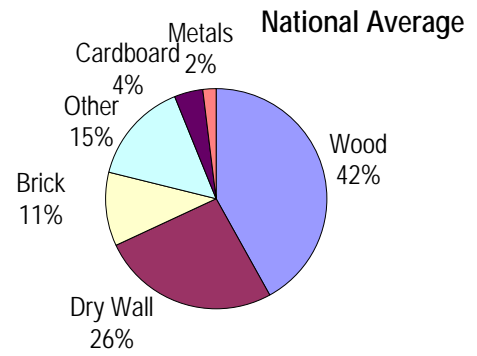


Figure 44. C&D waste-stream makeup

Waste stream disposal costs

The total expenditure for waste stream disposal costs totaled \$1,800; \$180 to set the two containers on the site and \$180 per haul for nine hauls.



Figure 45. Completed House One

Observations

Designing Out Waste

- Material quantities for building are significantly overestimated, therefore ensuring a waste stream.
- The utilization of bricks for facade and as an element of mass, when applied to the notion of 10 foot or greater wall sections, creates a geometric problem that can only be remedied by significantly more material.
- Complicated and complex elevations and roofing options lead to a large amount of brick and shingle waste.
- Bricks are oversupplied to the jobsite by a factor of about 15% to allow for quality, batch variation and breakage.

Jobsite

- A total of nine (9) dump truckloads of crushed concrete were purchased and applied to the site so workers could gain semi reasonable access.
-
- The slab contractor generally reuses wood from the forms for about four sites and dumps the waste wood at the fourth. Most of this wood was left on our audit site.

The Construction Process

- The days lost to rain are many and they are costly in terms of waste generation.
- Less than sixty days into the construction, after the initial seven truckloads of crushed concrete, another 2 dump truckloads were required to maintain access to the site.
- Total site cleanup costs are about 1% of the total sales price of the home, with 20% of that percentage being paid to the waste haulers. In this house that equates to \$ 2,000 for the waste company and \$ 8,000 paid to common laborers to effectuate the cleanup.
- Neither efficiency nor effectiveness were principles that were deeply held in this process of residential house building.
- Time is the one dimension that we observed the craftspeople valuing.
- The builder values profit first and foremost. If he can't make money he will not engage in the act.

Waste Estimation

- The EPA calculator tool is a workable, reasonable estimation tool based upon this data and H-GAC should make use of it for their purposes.

- Estimating volumes is not difficult to perform, if you are willing to accept a small margin of error.
- Volumes are dramatically affected by density.

Waste Plan Management

- Waste management is not specified as one person's job at the site.
- The foreman is the most important person in a C&D waste study.
- Given the choice, workmen will always choose virgin material over looking for scrap or surplus.
- The weakest link in the study in terms of cooperation, difficulty to work with, and communication was the waste firm.
- If you post notices in Spanish, workmen will read them.
- Hispanic workers will recycle when skilled Anglo tradesmen will not.
- If you provide waste receptacles on the jobsite and the foreman requires workmen to use them, they (the workmen) will.

Waste Hauling

- Clean wood waste is hauled to a wood recycling firm when the driver is instructed to do so by the dispatcher.
- There is a small underground economy in clean wood waste that is profitable.
- The cost to haul C&D waste is very small and represents less than 0.5% of the selling price of a home.

Opportunities for Improvement

- The "roach coaches" that bring the workmen breakfast and lunch, should be required by license to provide on the vehicle trash receptacles and recycling bins.
- The larger the waste container, the larger the temptation for everyone on or near the site to not be responsible about waste on the site.
- The public thinks that a waste container in the neighborhood is a free dumping zone. As a solution to remedy this problem, the threat of video taping illegal dumping should be exercised routinely.

HOUSE TWO C&D WASTE STREAM AUDIT

Overview

The plan from the onset for House Two was built around the concept of trying to dramatically reduce the amount of waste going to the landfill. The house was going to be of similar size as the House One Audit house (7,789 versus 7,929 square feet) and was going to be constructed by the same builder and sub contractors. In the intervening time from the onset of the audit of House One, HARC had investigated many alternatives including on-site separation, off-site separation, on-site grinding, transfer and a mixed approach. HARC floated the notion of evaluating one of the recycling methodologies we had found in the literature search, on-site grinding. HARC approached first the builder and secondly the H-GAC staff. Mr. Cox clearly stated his desire to try and find an alternative method to what he had always done with hauled waste.

HARC itself had become fully convinced that one of the early options considered, on-site grinding, was in fact a methodology that made perfect sense in the instance of this large custom home. We made Mr. Cox aware of the option, provided literature and set up a meeting with representatives from Belleau Wood Environmental, LTD., a Houston area business and its owner Mr. Joe Collett. HARC asked Mr. Collett to make a presentation to Mr. Cox on the on-site grinding methodology. As it turned out, this was a little more difficult to coordinate than we all thought.

Mr. Collett is a distributor for Packer Industries and a service provider for on-site grindings. Ultimately, Mr. Cox granted his consent to investigate and apply the methodologies of on-site grinding to the second site he had provided. He made his construction superintendent the prime contact and we had an agreement July 26, 2004 to begin the process. We then secured the permission of H-GAC to conduct this limited test of the methodology for evaluation. Mr. Collett graciously donated his time, his firm's labor, technical resources, and his knowledge to this project and the objective of testing on-site grinding in the H-GAC area.

During the months of July and August the site preparation and foundation work was taking place with sand, rebar, post tension cable and the forming lumber showing up on the site. The second house was located at 234 Angel Leaf, The Woodlands, Texas, Montgomery County. The house was a 7,789 square foot two-story house with a swimming pool. The slab was poured on August 3, 2004. According to the agreement the builder would conduct a version of on-site segregation of the materials jointly identified to be ground on-site: these were wood, cardboard, shingles, bricks and drywall.

It was also the case that on-site grinding would not and can not address every need in the new construction waste stream thus, there would be a requirement for the project to have a 30 yard roll off container in place to handle the material that could not be ground and applied (recycled) on-site. HARC contacted the waste contractor BFI, Inc. and ordered another container to be delivered. The roll off was set in place September 21, 2004.



Figure 46. Roll off container arriving at House Two

On-site Grinding - Grind One

The first day for experimenting with on-site grinding machinery was September 8, 2004. The H-GAC staff was invited to attend and witness the process in action. In accordance with the plan, the builder had segregated the wood waste stream on-site with the intention of expediting the grinding process on the grinding day. Mr. Tom Cox and Builder Bob, the construction superintendent, had done a great job assembling the foundation forming wood and the frame package wood wastes as well as some of the roof decking. Mr. Joe Collett, the President of Belleau Wood Environmental, LTD. arrived on-site with his crew and his grinding machinery. The device used in the test was a Packer Industries Inc. Model 750 grinder. Packer Industries is located in Mabelton, Georgia.

The site was holding about all of the solid sawn wood that it was capable of handling when the day began. In the figures below, the materials can be viewed quite easily. The builder had implemented his program of isolating the wood wastes on-site in anticipation of the grinding process. The builder was very creative in terms of where and how they stored the solid sawn wood waste. On this large lot this plan worked very well.



Figures 47 and 48. Solid sawn wood storage on-site anticipating the grinder

The materials were transported from their locations on-site to the grinder via a bobcat with a one cubic yard bucket. The size of the bucket is important because the intake throat on the grinder feeds a grinding hopper that has a one cubic yard capacity. The segregation of the wood makes the process move very quickly for the team and the entire process was observed with close scrutiny.



Figures 49 and 50. Bobcat and grinder with H-GAC staff

The table documenting Grind One shows two critical points. First, the volume reduction from bulk waste to ground waste is a little more than a 3 to 1 ratio and secondly, the grinder virtually eats the material quicker than one would imagine. The typical grind time for a three quarter yard load of wood was 4 minutes. It is the case that this particular machine makes use of a magnetized belt in the feeding process so that the post-grind wood is not contaminated with any metal wastes, whether it is nails or joist hangers. The metal is simply segregated out into a bucket for recycling with the appropriate metals recycler.

Due to the grinding, 53.75 yards of solid sawn wood primarily from the forms and frame packages was reduced to 17.67 yards (30% of original dimensions). This was accomplished in a total of 308 minutes of grinding time on the machine. Note that this is different than total elapsed time for the day of grinding. Additionally 8.5 yards of TechShield, a foil fronted radiant barrier manufactured by Louisiana Pacific, and cornice were reduced to 1.5 yards (18% of original) in 40 minutes of machine grind time.



Figure 51. Pre-grind wood



Figure 52. Post-grind wood.

**Figure 53. Pre-grind wood****Figure 54. Nails separated during the grind**

Alternative to Crushed Concrete for Site Stabilization

HARC and Mr. Cox had previously decided that the wood waste would be ground and applied directly on-site as a silt fence application, soil improvement, or as a general site improvement material. This was a conscious choice consistent with the manufacturer's recommendation and that of Mr. Collett. It is the case that some builders do harvest the ground wood and transfer it to another site or apply it to the site at a later stage. The philosophy behind the chosen and preferred tactic is that residential construction sites are notoriously known as mud pits where everyone struggles with the mud. The result of this struggle is that many days of work are lost as a result of the site conditions. In another study, researchers found that up to 16 days of time in schedule could be recovered when a wood chip mat was widely employed to create a working and lay-down area. Recall that in House One, that builder had to purchase nine (9) loads of crushed concrete to gain and maintain access to the site at a cost of more than 500 dollars. This was mainly for access and did nothing to provide working space for the workmen.

The ground solid-sawn wood made a superb mat upon which crafts of all kinds can work in the worst of weather. In light of this fact, this idea was always a part of the plan at this site. While HARC and the builder deployed this strategy at some level the plan but it was not as widely employed as HARC would have preferred. Thus, the actual cost benefit analysis from this approach can not be maximized in this investigation. Although HARC we can fully substantiate the value, the cost savings calculations do not yield the type of results we felt were possible when the mat is fully deployed for all trades on-site.

**Figures 55 and 56. Post-grind wood applied as a mud controlling mat**

The primary reason this underutilization took place was due to a miscommunication between some of the parties. In an attempt to be responsive, the builder asked that the decking, better known as TechShield, be ground so that the amount of material going to the landfill would be greatly reduced. He had seen the 3 to 1 reduction in the solid sawn wood and was favorably impressed. All present tried to discourage this particular request fearing that the material could become commingled with the clean ground wood. Nonetheless, it was done with the result being a partially compromised pile of ground materials and tiny pieces of tin foil in the most inconvenient places. Due to this commingling of material and concerns for the consequences, the amount of mat was reduced. This problem of tiny little pieces of TechShield would confound the project until the very end.



Figure 57. The mat being created



Figure 58. Post-grind TechShield

The data for the first grind is incredibly straight forward. The ground material is not a fine grind in the wood version but is more appropriately defined as a fine chip approximately 2 inches long and three quarters of an inch wide. The grind consisted of the foundation packages, frame packages, and the TechShield. 14,418 pounds of sawn dimensional lumber was ground in a total grinding time of 308 minutes. 2,403 pounds of TechShield was also ground. In House Two HARC employed the EPA calculator values for all weights used in the report and actual volumes from a log which was maintained by Belleau Wood Environmental, Ltd.

House Two Grind One

Type of Material	No. of grinds	Grind time (Minutes)	Average time per grind (Minutes)	Approximate Volume Pre-Grind (Yards)	Approximate Volume Post -Grind (Yards)	Volume Reduction (Yards)
Frame Lumber	72	308	4.27	53.75	17.67	3:1 ratio (36.08)
TechShield and Cornice	11	40	3.5	8.50	1.50	3:1 ratio (7)



Figures 59 and 60. Post-grind separated waste materials

Haul One

The container for House Two was set in place September 21, 2004. Haul One for House Two was completed on October 4, 2004; after the first on-site grinding took place. Haul one consisted of mixed wastes estimated at 2,166 lbs (22.8 cubic yards * 95 lbs/cu yd). The actual container was scaled at 2,120 pounds. The contents of this haul were of the most undesirable material and least likely to be recycled, possibly due to the grinding of the more desirable and recyclable materials. The haul consisted of wet cardboard, plastics, vinyls and painted wooden material.

House Two Landfill Waste

Date	Haul	Weight (lbs)	Details
10/4/2004	1	2,120	TechShield, packaging, sheathing



Figure 61-62. Commingled mixed waste contents of Haul One

On-site Grinding - Grind Two

The second grinding day was established as November 5, 2004. The H-GAC staff was again invited to the grind. The plan for the day was to grind the remaining solid sawn wood that been generated in the time since the first grind and the drywall pile. Belleau-Wood Environmental, Ltd., arrived at 234 Angel Leaf at 12:30 pm, and began grinding the leftover wood. Due to a

recent rain, the site was extremely muddy and there was an enormous puddle near the drywall pile. To solve this problem, the mulch produced from the wood grind and several scoops of the mulch pile from the earlier grind was used as a mat or pad for the bobcat. The mulch mat allowed easy access for the bobcat to the drywall pile and the grinder and generally made the site much neater.

The brick-laying crew, which was mixing mortar behind the house and carrying it into the house in a wheelbarrow, was greatly aided by the mulch mat walkway. After the pad for the bobcat was constructed, the drywall grind began. The grinder rapidly reduced the drywall pile to about one third of its original volume, and the post-grind material was moved to a pile in the backyard. The grind was really rather easy, even more so than the first grind. 11,600 pounds of drywall was ground and an additional 6,608 pounds of post-grind wood was made available for the site.

House Two Grind Two

Type of Material	No. of grinds	Grind time (Minutes)	Average time per grind (Minutes)	Approximate Volume Pre-Grind (Yards)	Approximate Volume Post -Grind (Yards)	Volume Reduction (Yards)
Wood	40	156.5	4	24.75	8.14	3:1 ratio (16.61)
Dry Wall	39	13.87	3.5	28.75	7.13	3:1 ratio (21.62)



Figures 63 and 64. Solid sawn wood waste for Grind Two



Figure 65. Mr. Collett on the grinder



Figure 66. Mat being created

The second grind of wood was accomplished in 157 minutes which is a little more than half of the time that was spent in Grind One. In this grind, 6,608 pounds or 24.75 cubic yards of material was reduced to a little more than 8 cubic yards of useful material which could be immediately deployed on-site as demonstrated by what had taken place in the set up for the grind. In grind one, 14,351 pounds of solid sawn wood was ground in machine grinding time of 308 minutes.

From the observations made of the grinding process, the following conclusions can be drawn. First, the grind time for a hopper of solid sawn wood is less than 5 minutes. Second, the volumetric reduction that the grinder provides is greater than 3:1 creating a resource of the material instead of a liability.

The second phase of grind two was to address the drywall on the site. Again, the builder did a great job of storing the waste on-site in preparation for the grind. Approximately twenty-nine (28.75) cubic yards of drywall was on the site that day. The grinder performed beautifully grinding the material into a combination of fine and chipped pieces. To minimize the drywall dust that is created when the material is ground, the machine is fitted with a drape that contains the material in the immediate area of the machine. The grinding time for the 29 yards was under 14 minutes of machine time.



Figure 67. Stored pre-grind drywall



Figure 68. The grind pile



Figures 69-70. Post-grind drywall ready to be applied to soil

Haul Two

The Haul Two container left the site on November 29, 2004. The container consisted primarily of brush from site clearing, including understory/brush and small trees, mortar, TechShield, and wet cardboard packaging. The container load was a full 30 cubic yards. HARC applied the calculator and estimated a total weight of 4,170 pounds. The container was composed of: (1) mixed wastes (20 yards * 95lbs/yd), (2) engineered wood (4 yards * 280 lbs/yd), (3) mortar (1yard * 1000 lbs/cu yd) and (4) cardboard (5 yards * 30 lbs/cu yd). The container passed the scales at 4,000 pounds.

House Two Landfill Waste

Date	Haul	Weight (lbs)	Details
11/29/2004	2	4,000	Brush, mortar, cardboard



Figure 71. TechShield with foil



Figure 72. Mixed wastes



Figure 73. Wet Cardboard

Haul Three

The third and final 30 yard roll off container haul for house two was transported to the landfill on January 5, 2005. The container was very full, consisting primarily of mixed wastes from the final lot clearing, the final understory clearing, and the final house cleaning that had taken place during the holidays. We did not attempt to estimate the weight of the container due to the nature of the site cleanup materials.

House Two Landfill Waste

Date	Haul	Weight (lbs)	Details
1/5/2005	3	7,100	Understory clearing

**Figures 74 and 75. Contents of Haul Three***On-site Grinding - Grind Three*

Grind Three took place after the holidays and after the final roll off container had been hauled. The builder had advised HARC that he was ready to finalize the grind and to get the buyer into the home. The grind was scheduled for January 11, 2005. The H-GAC staff was invited to attend but was unable to make this grind. There were some non-grinder mechanical problems that did not allow the grinder to arrive on-site until after twelve noon on the day of the grind. Thus, the grind actually took place over the course of two days. The builder again had done a terrific job of stacking and storing the material to be ground. This grind was dedicated to the reduction of the waste from shingles, bricks, final wood trim and site wood cleanup.

**Figures 76. Pre-grind brick & shingles 77. Hopper loaded****78. Loading shingles**

There was a great deal of interest in the ability of the grinder to handle the shingles and the bricks using the one cubic yard hopper. These are two very unique materials with properties that might present challenges to a portable grinder. The grinder performed excellently throughout the grind turning bricks into a fine powder and shingles into small shards of asphalt.



Figure 79. Palletized pre-grind brick



Figure 80. Stored pre-grind brick



Figure 81. Stored brick



Figure 82. Taking bricks to the grinder

The ease with which the site was cleared was a testament to well trained craft persons and a desire to have a job well done. The employees of Mr. Collett worked effectively and efficiently and the bricks were reduced in very little time into a perfect base material for the concrete flatwork that was to follow the grinding day. The functioning of the tractor versus the bobcat was entirely more flexible and was more effortless in loading the hopper. This was an observation shared with the crew and there was tacit agreement that the height of the tractor did aid in speeding along the feeding of the hopper with material to be ground.

There was a remaining feedstock of wood, primarily trim, and some forming material that had to be ground. Having already observed this process and knowing what the grinder was capable of doing; HARC turned its attention to the matter of the application of the materials on site. It was the case that all previous materials that had been ground had been applied on the site with one notable exception: The TechShield. A pile of ground and commingled wood lay in the back yard. This issue had to be addressed. In discussion with the builder a month later it was decided to harvest the material and to landfill the TechShield.



Figure 83. Grinding of bricks



Figure 84. Metal harvested

House Two Grind Three

Type of Material	No. of grinds	Grind time (Minutes)	Average time per grind (Minutes)	Approximate Volume Pre-Grind (Yards)	Approximate Volume Post -Grind (Yards)	Volume Reduction (Yards)
Wood	18	63.93	4	18	5.94	3:1 ratio (12.06)
Shingles	7	13.87	2	7	2.31	3:1 ratio (4.69)
Brick	32	77.32	2.50	32	10.56	3:1 ratio (21.44)



Figure 85. Close-up of post-grind brick

Summary of House Two

In total, the house generated 87,556 pounds of C&D waste. According to the national average based on NABH studies, a typical 2,000 square foot house generates 8,000 pounds of waste. This is verified in previous studies and confirmed in the Franklin report. This house was 7,789 square foot, two story. If we were to extrapolate the 2,000 square feet to 8,000 square feet one would expect something on the order of 32,000 pounds of C&D waste.

House Two Total Landfill Waste

Date	Hauls	Weight(lbs)	Yards
10/2004-1/2005	3	15,490	84.3

This house, however, will not sustain the 87,556 pounds of waste. Because this house utilized the on-site grinding methodology, the house diverted 72,066 pounds of waste from the landfill to its site. This is a diversion rate of 82.30 %. This is a very replicable result for any residential house and is entirely consistent with the national on-site grinding studies cited earlier.

House Two Total Grind

Type of Material	No. of Grinds	Approximate Volume Pre-Grind (Yds)	Weight (lbs)	Approximate Volume Post -Grind (Yds)	Volume Reduction (Yds)	3:1 Ratio
Wood	130	95.50	25,766	33.17	62.33	0.34
Shingles	7	7	2,800	2.31	4.69	0.33
Brick	32	32	32,000	10.56	21.44	0.33
Drywall	39	28.75	11,500	7.13	21.62	0.24
TechShield	11	8.50	2,261	1.50	7	0.17
Total	219	171.75	74,327	54.665	117.08	

The pie charts in Figures 86 and 87 below depict the ratios of waste make up for the study house and the national typical house. One of the striking differences in the two charts is the more than 327% increase in the brick component of the C&D waste stream. This is entirely consistent with what was observed in House One. This is significant inasmuch as, according to the EPA calculator, bricks weigh an estimated 1,000 pounds per cubic yard.

The fact that H-GAC area's modern hot and humid houses typically are built with a significant increase in the volume of enclosed space (this was a two story home) leads to this surprisingly large increase in the amount of material required to create the envelope and the resultant interior components such as drywall. This is simply a function of geometry that builders are forced to deal with in this marketplace. To illustrate this point consider the following example, if a wall section is 10 feet high in a modern hot and humid climatic zone house and the comparison circa 1996 national typical is an 8 foot wall section, then 25% more material is required to cover the same square footage of space.

The fact that there is a substantial variance from the national typical model should not come as any surprise due to the response to climatic differences in the nation's typical house versus the typical

house in the hot and humid area. The surprise comes in the enormity of the variance. It is curious that the shift in materials (-26%) away from wood and drywall is fully accounted for in the increase in the percentage of bricks and masonry used. We have some opinions about the possible causes of the variance and suggest them in the following observations section.

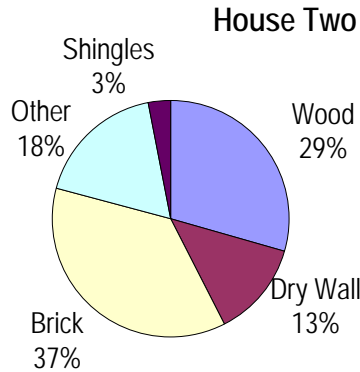


Figure 86. C&D waste-stream makeup

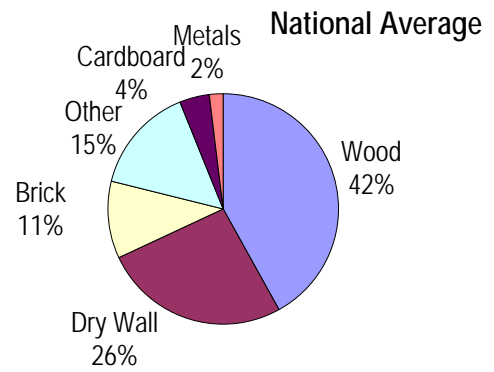


Figure 87. C&D waste-stream makeup

Waste stream disposal costs

The total expenditure for waste stream disposal costs totaled \$630; \$90 to set the containers on the site and \$180 per haul for three hauls.

On-site grinding costs were not incurred by the project. Mr. Joe Collett, of Belleau Wood Environment, Ltd. Donated the services and the consulting to the project to achieve the grinding of the materials. The manufactures suggested retail price for grinding is \$0.50 per square foot. If the project were to have incurred the cost the outlay of funds would have been, \$3,895.



Figure 88. House Two at completion



Figure 89. Backyard of House Two

Observations

- On-site grinding as a process and concept does work.
- On-site grinding on a large custom house building site is practical.
- The cost of on-site grinding at \$.50 a square foot is a value proposition that needs help.
- On-site grinding of wood and drywall create a great soil amendment material for most of the areas soils, and provides a monetary offset.
- On-site grinding of asphalt shingles is a very efficient use of manpower and is a very practical application of materials that provides a monetary offset.
- On-site grinding of bricks makes a very good base material that does provide a monetary offset.

Plan execution

- Electing to grind the TechShield in the middle of the wood grind was a mistake.
- Not insisting upon building the entire wood mat possible and soon as possible was a mistake.
- Transferring what we learned about the grinding process to production builders would be of limited value due to the very small lot sizes they build on.
- Skilled mechanical operators are required to maximize the power and speed of the equipment.
- Wet cardboard does not grind very well.
- Packaging waste is still considerable as a function of volume in a house of this size.
- We did observe men working on rainy days on the wood mat and following rainy days on this site when they were no men working on nearby sites.
- The changes in The Woodlands Operating Companies enforcement of their deforestation policy lead to a massive amount of green waste very late in the project.
- The builder did an excellent job of sorting and storing the materials for the grinding process.

Conclusion

C&D waste in large custom houses is greater by an exponential factor than the national typical house. The cost of C&D waste hauling in this immediate area is a mere fraction of the builders cost and the hauling costs represent no more than 20% of the total cleaning costs the builder incurs. Thus, there is little current incentive to recycle. The barriers are manifold and the culture is not favorably inclined to change due to the economics of the situation. The cold hard fact that drywall has no marketplace in the state of Texas is a huge barrier to overcome for the H-GAC area. The solid sawn wood and the engineered wood with no foil applied are basically being recycled in an underground economy in which the builder does not participate in. In developments that require the use of a container to house the C&D waste, the policies actually encourages more total waste and promote neighbor/citizens to behave in an inappropriate manner.

On-site grinding is technically a very viable option. The fundamental difference an on-site grinder in the waste stream reduction makes is too large to ignore. Waste stream reduction rates of more than 80% can and should easily be accomplished. The economics of on-site grinding are close to being viable but do not exist as of today. There are now three on-site grinding companies in the H-GAC area. Two of these sources are in the grinding business because the ownership is enlightened and wants to do the right thing. The third is a part-time business that primarily is involved in the sale of the grinding equipment.

A brief review of the study follows:

House One compared to House Two in Macro Numbers

There were 9 container hauls versus 3 container hauls in house two

There was 85,242 pounds of C&D waste in the landfill versus 13,220 pounds in House Two

The builder had to purchase 9 loads of crushed concrete, mulch, and fill for the lot versus house two, where the reuse of the waste from the house was used for these purposes and no additional material had to be bought.

The builder lost days due to rain in house one versus house two where the wood grind mat allowed craftsmen to continue working

The waste stream for House One

Crushed Concrete

Nine dump trucks of crushed concrete were purchased to control mud

Cost: \$500

Nine 30 cubic yard containers were filled; 3 of wood only; 1 of drywall only, and 5 commingled

Costs for House One:

-9 (landfilled) x \$180

-2 (settings) x \$90

Subtotal: \$1800

Total Cost \$2300

The waste stream for House Two

No crushed concrete used, ground wood used instead

3 containers were filled; all commingled.

Costs for House Two:

-3 (landfill) x \$180

-1 (settings) x \$90

Subtotal: \$ 630

Utilizing on-site grinding (donation) valuation set by current list price at \$.50/per square foot

Cost: \$3900

Total Cost \$4530

There are other monetary considerations which would vary from project to project. Examples include silt fencing, Fill material avoidance, base material avoidance, and most significantly the number of days that skilled craftsmen can continue working due to the conditions of the lot. HARC has not attempted to quantify those potential savings due to the jobsite unique nature of the savings. Previous studies on on-site grinding have not tackled this problem either. The most famous of these is the Indiana study conducted by the NAHB. In this study, the costs of land filling alone made the on-site grinding economically feasible.

The cost of the fill material and the base material is a hard dollar number that the builders can factor and consider in their decision making.

Simply put, Houston area landfill costs are so low that if the test of economic feasibility is the only one then it will be at some future date that on-site grinding becomes the predominant method of addressing the C&D waste stream.

In the instance of House Two, if we use only the metrics of landfill costs versus grinding and if we assume that 9 hauls is the correct number, the costs per cubic yard of waste would have to be \$14.44 a cubic yard and a 30 yard container would have to cost \$433.

The application of crushed concrete, a recycled product, is very common in our area. In the instance of House One, the application was a \$500 expenditure. If we factor that into the equation, then the "per cubic yard cost" can be lowered to 12.60 or \$378 per container. This remains more than double the current Harris County landfill rates.

In some respects builders should not have to worry about facing the dilemma of paying for containers and materials versus paying for grinding, they should be provided the most responsible method of waste handling by the scientific community. This has not happened and is unlikely to occur due to the fractious debate over a dollar today and long term costs.

When builders have large containers on-site, there is a tendency to generate more waste because of the “out of sight out of mind” philosophy. It also is unquestionably the case that large containers represent an open invitation to the general public to dump their household waste, regardless of the law, the threat or the signs which say smile you are on a closed circuit camera.

On-site storage in anticipation of on-site grinding may not be practical in large tract developments or dense sites unless the entire builder community agrees to the methodology. A more aggressive waste management plan will need to be employed to minimize the amount of waste left on-site with the associated potential risks and the cleanliness and tidiness perception issues raised with potential buyers.

Wood waste ground into mulch can be used in a variety of ways on a residential construction sites with very positive results. The most direct of those positive results are:

- Erosion control material for disturbed areas
- Mulch berms to aid or replace silt fencing in erosion control for the site
- Protecting Tree Root Zones
- Road and walkway stabilization for crews
- Landscaping, and
- Workmen’s mats or pads

The main component of sheetrock or drywall is gypsum. Gypsum has been used as a soil amendment for hundreds of years particularly in heavy clay soil areas like that confronting the Houston area. Drywall will and can add nutrients to the soil such as calcium and sulphur without raising the PH of the soil. The US Department of Agriculture has called this material a resource that can be used to help establish the lawn around the new home. H-GAC should consider a specific education program for on-site utilization of drywall.

Shingle waste is a perfect source of base material for the flatwork on most new home construction building sites. H-GAC should consider a specific education program for on-site utilization of asphalt shingle waste.

Brick waste the single largest and most difficult to handle of the wastes in these studies needs to be seriously examined. The entire process needs to be subjected to a quality control cycle review. Builders could dramatically reduce their first costs by addressing the over specification of quantity and remove the safety factors that have to be part of the equation. The factories should be approached about take back contracts. If brick manufacturers over supply the material, the manufacturers should be encouraged/required to go back to the manufacturer for redistribution. HARC believes that there is little difference between a battery, a tire, or brick in the context of solid waste. The current practice is very expensive in the short and long term. The process is ripe with the opportunity to be improved.

Summary

Understanding the huge amount of waste in these homes has been a difficult task. One would expect that, relative to material use, there would be an economy of scale as house size increased—that material use per unit area of floor area would drop as floor area increased. It has not been made any easier with additional research. The most normalized metric in the data is pounds of C&D waste generated by the square foot of constructed space. In house one, 85,242 pounds was generated for 7,929 square feet of building space. This house generated 10.75 pounds of waste per square foot. The second house generated 87,566 pounds of waste, 11.04 pounds per square feet but 72,066 pounds of that waste was diverted from the landfill. This equates to a diversion rate of 82.30 %. The fact that the diversion took place at such a high rate is a testament to the potential of on-site grinding. The fact that there was 87,566 pounds of waste is horrific.

There are seven reasonably well conducted studies that are recent in the literature. NAHB conducted four of those studies; one in Oregon, two in Maryland, and the last in Michigan. There is one house in Illinois, and a 9,000 square foot apartment complex, and one house studied by Cornell University in New York. The average amount of waste per square foot in these studies was 4.44 pounds per square foot. The range is from 2.46/lbs per sq ft at Cornell to 7.2lbs/sq ft in the Illinois house. By any standard it could be said, “Houston we have a problem.”

HARC’s contention that the bricks and mortar are the most significant contributor to the variance between the Houston houses and the national data models is supported with an examination of the waste components of these seven houses. Wood waste averaged 39.7 percent of total C&D waste in these houses. Wallboard averaged 29 percent, and cardboard 5.4 percent. This accounted for 74.1 percent of the total waste. Our argument is supported by the fact that there is no brick data reported for any of the houses in these studies, and further there is no data collection for asphalt shingles.

As HARC observes in this study, the National Association of Home Builders (NAHB) is uncovering and reporting similar findings. Although NAHB has not compiled data on material use as a function of house size, NAHB believes that, because larger houses tend to have taller ceilings and more features, larger houses may consume proportionally more materials. NAHB estimates that a new 5,000-square-foot house will consume three times as much material as the 2,082-square-foot house NAHB has modeled, even though its square footage is only 2.4 times as large. Total wood use in houses increased steadily between 1950 and 1992, as houses grew in size. But when total wood use per unit of floor area is examined NAHB found that it dropped between 1950 and 1970—perhaps due to the substitution of plywood sheathing for board sheathing and the introduction of more wood-efficient roof trusses. Then, around 1970, wood use per square foot of floor area began to increase again, and by 1992 it was up about 12% from the low point. HARC would argue that with this increase in total usage the total waste numbers have become exponential as previously stated. HARC also believes that the design shift to more complex geometries to create the “starter castles” that the Houston public is predisposed to demand contributes to the massive amount of waste produced per square foot.

HARC can only hope that this study can assist H-GAC in informing the builders and the public in obtaining more information about what might be possible in lieu of a continuation of the status quo with regard to new residential C&D waste practices. HARC’s fear, based upon our interaction in

the building community, is that this issue lacks traction. The builders, are like most of the Houston population, are largely uneducated about the environment and largely disconnected from the consequences and the implications that something so insignificant to their core business as C&D waste could have on ecosystems and the quality of life in the region. Let us remind the reader that C&D waste handling is less than 1% of the selling cost of the home they are building. Builders are businessmen first and foremost. The buying public is not creating any market pressure to handle C&D waste in a more responsible manner. The builder's are not advising builders that more responsible C&D waste handling will lead to better short term interest rates. Land developers are not requiring builders to handle C&D waste in any particular manner. Their perspective is cleanliness only and these developers de facto may make the situation worse by requiring large roll off containers. Builders are not facing any impending shortage of landfill space as confirmed by the latest published studies. The waste haulers are not providing price increases that would cause any builder to consider alternatives to the way they have always done it. Regulatory agencies are not publicly talking about any regulatory change that might induce builders into action be it to fight the change or be it to alter their practices.

The HARC summary of the issues, concerns, barriers, and changes in practices elsewhere in the nation clearly lead HARC to believe that the issue of C&D waste handling practices in the H-GAC area will ultimately change. However, it is our opinion that this will not occur in the short term and certainly no sooner than seven years in our area.