Sustainable approaches to landfill diversion: the global sustainability of deconstruction

Dr. Eddy Smith
United States Army Corps of Engineers, Engineering Research and Development Center-Construction Engineering Research Laboratory-Champaign, IL, USA

Mr. William E. Boone
Concurrent Technologies Corporation-Largo, FL, USA

Dr. Mamar Shami
University of the Pacific-Stockton, CA, USA

ABSTRACT: This paper provides analysis that higher diversion rates of construction and demolition (C&D) waste from the U.S. landfill sites are not only good from a sustainability standpoint, but also an achievable goal. When deconstruction occurs, proper planning should start to take advantage of all technologies and processes available for recycling and reuse along with emerging markets for transformed C&D materials. The data collected and analyzed in this paper suggest that the benefits of increasing C&D diversion rates resulting primarily from deconstruction projects will have tremendous positive impacts on having a sustainable future, which includes energy production, virgin materials, end items, and processed materials. Deconstruction projects of the Department of Defense (DoD) military installations are analyzed in detail in this paper. Although the DoD has been pioneering many C&D solid waste management projects to reap the benefits of high diversion rates from landfill, there have been discernible efforts by the industry to attain diversion rates as high as 90% in many instances.

1 INTRODUCTION

Deconstruction is a relatively new term that refers to the process by which a building is disassembled in a reverse order to the process of construction. The term was originally used around the mid-nineties in a meeting of the Used Building Materials Association (UBMA). Deconstruction, as opposed to demolition, is considered an organized and systematic method, as materials need to be separated at the source in order to maximize landfill diversion through reuse and recycling. At first, there was no distinction between reuse and recycling of construction and demolition (C&D) waste. Manual and mechanical separation helps increase the rates of reuse and recycling and thus increasing diversion from landfills. During the late nineties, the Environmental Protection Agency (EPA) suggest a modest recovery and diversion of C&D waste to be 20 to 30%; however, other organizations such as the National Association of Home Builders (NAHB), the military, and other non-profit deconstruction organizations have already aimed or achieved a diversion rate of 90% in some instances.

The costs associated with demolition of old facilities such as buildings, warehouses, roads, power plants, and others through hauling debris to landfills can be tremendous. Tipping fees are only one piece of the puzzle, but the environmental impacts and long-term effects of dumping C&D waste directly into the landfill on water, land, and air can be daunting. The social, political, and environmental pressure to increase reuse and recycling, and thus maximize diversion from landfill, are often counterbalanced by economical and technical perspective. For example, California's Integrated Waste Management Act of 1989 established a goal of 50% diversion rate of all municipal solid waste (MSW) that includes C&D by the year 2000 [Guy 2004].

The benefits of landfill diversion are highly noticeable when it comes to the environment. This can be seen given the fact that over 60% of all non-food and fuel raw materials consumed in the US are actually consumed by the construction industry according to the US Geological Survey. On the other hand, out of the nearly 4 billion tons of new materials that flow into the market each year, nearly 200 million tons are from renewable sources. For example, wood recovered from deconstructed buildings could supply just about a quarter of the lumber supply for the housing construction industry over the next fifty years, thus greatly reducing the amount of landfill space [Anderson 2000].

The sustainability of deconstruction lies in the fact that reducing amounts of C&D waste that were traditionally destined to be landfilled will conserve valuable land space and help minimize the negative impacts of waste on the ground, water, air, soil, and forest. This process is also emphasized by supplying the market with newly recycled and reused materials, which relieves the demand on virgin materials.

This paper provides an overview of the strategies used to manage C&D waste. From policy and regulation to pricing and codes, there have been tremendous activities over the past ten years in the area of C&D waste management, which resulted in an increasing rate of diversion of C&D waste from landfills. This can be attributed to increased awareness and education, enhanced market perception, high tipping fees, etc. A methodology is presented in this paper to illustrate how deconstruction can have a positive impact on the environment. The data collected to implement this methodology covers cost aspects and social issues. More importantly, the technologies and type of materials that are considered for reuse and recycling were emphasized. A thorough investigation was conducted about the processes that building materials go through to close the loop from deconstruction back to the construction and renovation industry.

2 THE SOLID WASTE MANAGEMENT HIERARCHY

When proper C&D waste management strategies are practiced, C&D waste can be considered non-hazardous, and as a result can be managed more efficiently before it reaches the landfill prior to disposal. More than any time in the history of waste management, a number of options is available to C&D waste planners and managers throughout the life cycle of a structure. These options can be illustrated using the following hierarchy as shown in Table 1.

Table 1. Hierarchy of solid waste
C&D Waste Management Hierarchy - Opportunities

	Planning	Design	Constr	Opt.& Maint.	Decon.
Reducing	L	M	H	L	L
Reusing	L	M	H	L	H
Recycling	L	M	H	L	H
Composting	L	M	L	L	H
Incinerating	L	L	L	L	H
Landfilling	L	L	L	L	H

As shown in Table 1 above, the opportunities for reducing waste start early in the planning phase, and increase during the design phase and rise significantly during construction. These opportunities tend to be lower during the operations and maintenance phase as the generation of C&D waste tend to be lower unless a major renovation or upgrade takes place. Material reuse can be implemented in the design and construction phases as a large number of alternatives are available from using recovered (reused) bricks, tiles, wood, appliances, etc. in the new facility.

To increase the potential for sustainable opportunities during the six life cycle phases shown in Table 1, various strategies can be considered. In the planning phase, the options range from choosing simple plans with standard building components to the use of prefabricated items that would enhance the reusability and recyclability. The latter issues can also be enhanced by using non-hazardous materials and items with recyclable content. There are tremendous opportunities for the implementation of waste reduction and reuse during the construction and deconstruction phases. Materials sorting, separation, and handling for reusable materials for resale can all contribute to the overall goal of sustainability through responsible C&D waste management strategies.

3 METHODOLOGY FOR MANAGING C&D SOLID WASTE STREAM

A framework for deconstruction as related to its impact on sustainability, to identify and incorporate sustainable technologies, and strategies of deconstruction is presented in this paper. The framework draws upon issues related to materials reuse and deconstruction strategies to study their environmental impacts. In addressing the sustainable building removal options, three of which this research tracks, have been looked into including the process of deconstruction in relation to C&D

materials processing techniques as related to reuse and recycling, and the environmental issues that can result when structured and well planned deconstruction programs are undertaken. The obvious outcome of such programs would be the reduction of waste that used to be discarded in landfills. Therefore, landfill diversion becomes the focal point of this research because it can be an indicator of how successful sustainable building strategies are, which includes deconstruction as shown in Figure 1.

METHODOLOGY
Deconstruction and its Global Impact on Sustainability

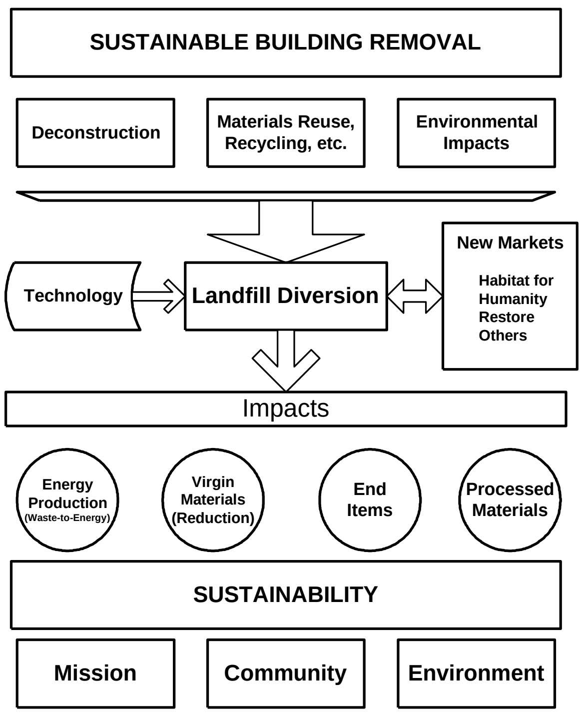


Figure 1. A Methodology for solid waste sustainability (SWS) of deconstruction.

4 CAVEATS OF SUSTAINABLE BUILDING REMOVAL

4.1 *Markets*

The demand for salvaged materials is another issue associated with deconstruction and recycling of building materials. In the article of "In Business" by Diane Greer, it is stated that 200 reuse stores are in operation nationwide. For example, the Rebuilding Center in Portland, Oregon is a 62,000 square foot warehouse employing 15 people and selling 1.8 million pounds of materials each month. An estimated 250 customers visit this warehouse everyday. In addition, the Massachusetts Directory of Recycled Product Manufacturers list 173 firms that employ over 12,000 people responsible for handling nearly 3.7 million tons of recycled materials each year. Recycling would not only benefit the environment, but also the general public [Greer 2004]. According to the Institute for Local Self-Reliance, the deconstruction industry has the potential to generate as many as 200,000 jobs in the United States [ILSR 2001].

According to the US Department of Housing and Urban Development, there are two types of deconstruction: structural and non-structural. Non-structural deconstruction requires less equipment and safety considerations and can be accomplished within hours or days. On the contrary, structural deconstruction takes more time and requires more in terms of tools and safety precautions. There are also two types of end-markets. High-end markets focus on architectural antiques and salvage and low-end markets deal with materials used for maintenance and replacement purposes. Non-structural deconstruction has both low-end and high-end market potentials whereas structural deconstruction mainly supplies the high-end markets [USHHUD 2006].

The appreciation for antiques has created new markets, which simultaneously make deconstruction a more cost-effective practice. For example, the demolition of the Capital Area East End Office Complex Block 171-174 allowed the recovery of 706 tons of old bricks that were sold for $12-15 per ton and segregated metals were salvaged for $25 per ton. For this specific project, the labor costs were partially offset by the revenue made from the salvaged materials [CIWMB 2006a].

4.2 *Educate, inform and change mentalities*

The hardest part of making deconstruction a common practice is to change contractors' mentality regarding this industry. For instance, Habitat for Humanity Reuse store in Kansas City, Missouri, used to receive 75% of their donation from individual homeowners or small landlords, but a year later and after some efforts made by the company program manager, Brian Alferman, nearly 50 % came from retail businesses and contractors rather than individual home owners. Furthermore, according to Ann Marie Aguilar, President of Environmental Sustainable Design Solutions of New York, "companies want to save money, they do not care about green design and they do not care about reducing materials going to landfills. You need to show them the savings." Ted Reiff, President of The Reuse People in Alameda, California, emphasized this idea by mentioning that one day of demolition is equivalent to seven or eight days of deconstruction. Therefore, to encourage contractors to choose this method, the benefits of cost savings need to exceed the disbenefit of a longer schedule [Greer 2004].

In the June 2002 issue of *College Planning and Management*, an article showed how the University of Texas tried to make deconstruction a more common practice. The old Graduate School of Biomedical Sciences was a 37,368 square foot building built in 1974 that was scheduled for either deconstruction or demolition. With low landfill costs and cheap land in Texas, it was difficult to argue in favor of deconstruction. Indeed, the average rate for a local landfill was $9.95 per cubic yard. However, with strong determination from the group leaders, the building was deconstructed and the recycling goal was exceeded reaching a rate of 77%. This project should stand as an example to show how deconstruction and recycling can be cost-effective and beneficial to the environment. In addition, in the May-June 2005 issue of *Construction and Demolition Recycling*, W.K. MacNamara, a demolition company in Walkham, Massachusetts, was trying to build the first C&D recycling plant for the company. It was believed that there was an existing market for salvaged materials and that is why this company is expanding in this direction [HEGYESI 2002].

4.3 *Perception of salvaged materials*

According to an article by Bob Falk, wood in older buildings is easier to disassemble because prior to the 1960's, adhesive was not used extensively. In addition, wood covered with lead-based paint cannot be reused because of toxicity. Quality of the salvaged material represents another issue. As a matter of fact, the standards set for the grade stamp were developed for virgin lumber and as a result, recovered wood cannot be graded and can only be used for non-structural and low-market applications [Falk 2002]. Forest Products Lab (FPL) is currently researching solutions to this problem with a grant of $650,000 from the State of Wisconsin [Forest Products Journal 2002]. Another issue affecting the integrity of the wood is caused by the removal of nails and fasteners. In the Netherlands, standards for reuse of materials such as concrete have already been developed. Nearly 20 % of natural gravel can be replaced by a secondary aggregate [DORSTHORST 2006].

As deconstruction is emerging as a commonplace industry, architects and builders did not anticipate such evolution a few decades ago and therefore, many of the buildings are difficult to take apart. According to the University of Florida, the Internal Council for Research and Innovation in Building Construction (CIB) Task Group 39 has conducted a 4-year study of deconstruction in order to exchange information with researchers and practitioners worldwide.

In the July-August 2004 issue of *Construction and Demolition Recycling*, the challenges to deconstruction by percentages were as follows:

- Education 19.4%
- Markets 13.9%
- Costs of labor 11.1%
- Environmental regulations 11.1%
- Perception of low quality 8.3%
- Storage needs 8.3%
- Damage to wood & contamination by nails 5.6%
- Disreputable business & unregulated activities 5.6%
- Insurance and workman's compensation for demolition and recycling business 5.6%

To enhance these outcomes, it is essential to educate about deconstruction, increase safety, and provide financial incentives in order to motivate contractors to opt for deconstruction and recycling practices [GUY 2004].

4.4 *Longer schedule*

To show that the time factor of deconstruction can be accommodated, deconstruction companies deconstructed a 1000 square foot 1920's home in 12.5 hours, requiring 26 workers. The total cost for the building removal was $7800 with labor costs of $5800. The salvaged materials created a revenue stream of $12,000 [PRIMDAHL 2002], [FALK 2002].

4.5 *Limited supply of used materials*

Some companies are reluctant to financially support warehouses selling salvaged materials because of the variability of supply. However, military bases represent a large supply for the reused material markets. Table 2 shows reuse and recycling rates for both residential and military structures ranging from 40-95%. Military buildings can recycle 60-90% of their materials. Considering the size of the forts and other structures, these materials can provide enough supply to run a warehouse. In addition, according to the Florida Center for Solid and Hazardous Waste, around 300,000 buildings are demolished each year, generating a great quantity of waste that could be reused or recycled.

Table 2. Reuse and recycling rates

Location	Case Study	Reuse/Recycling Rate	Reference	Website
San Francisco, CA	Presidio	87%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Fort McCoy, WI	US Army Barrack	85%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
San Diego, CA	US Navy Motor Pool Building	84%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Marino, CA	Fort Ord	80-90%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Twin Cities, MN	Army Ammunition Plant	60-80%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Baltimore, MD	Four unit residential housing	76%	Kibert et al. 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Port of Oakland, CA	Warehouse	70%	Kibert et al, 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Minneapolis, MN	Residential building	50-75%	Kibert et al, 2000	http://www.bcn.ufl.edu/iejc/pindex/109/chini.pdf
Hampton, VA	Fort Monroe deconstruction	75%	HR Clean	http://www.hrclean.org/Deconstruct.shtml
Colorado	Fort Carson Bldg 6826	40%	Report on Buildings 6286 and 227 prepared by Kuykendall	http://www.ubma.org/resources/articles/?article_id=26
Monterey, CA	Fort Ord deconstruction	90%	BioCycle, Nov 98, p. 46, by Dave Block	http://www.deq.state.or.us/wmc/solwaste/cwrcwrstrategy/deconrecyclnews.html
Gainesville, FL	Total hand deconstruction of 816 sf wood stud framed bldg	76%	Florida Center for Solid & Hazardous Waste	http://www.floridacenter.org
Baltimore, MD	2000 sf residential bldg	30%	Florida Center for Solid and Hazardous Waste	http://www.floridacenter.org
Amity, OR	Meeker Seed & Grain Mill deconstruction	95%	Architecture Week	http://www.architectureweek.com/2002/0529/building_1-2.html
Mildford, MA	Spruce Street Fire station demolition	89%	GreenGoat	http://www.greengoat.org/pdf/Milford_Fire_Station_Fact_Sheet.pdf
Salem, OR	Marion County Senator Block	82%	EPA	http://nepis.epa.gov/
Hartford, CT	Stowe Village	50%	EPA	http://nepis.epa.gov/
Lakewood, CA	Deconstruction of Regency Theatre	97%	Article in Construction & Demolition Recycling	www.allbusiness.com

4.6 *Incentives*

Tax benefits be used as an instrument to stimulate deconstruction. For example, the Chelsea Center at the University of Massachusetts introduced the Recycling Based Economic Development Grant Program, which can help fund a project by providing up to $25,000 per project [BIOCYCLE 1999]. In addition, the Massachusetts Department of Environmental Protection in Boston offers the following financial incentives to divert C&D waste [Allison et al. 2002]:

- The Recycling Industries Reimbursement Credit grants can provide up to $150,000 to companies that process or use C&D debris.
- The Recycling Loan Fund now offers low-interest loans up to $500,000 for C&D companies and has lent $525,000 since 1996.
- The Technical Assistance Grants provided $130,000 to municipalities to promote C&D diversion.

Another solution to counter balance the higher upfront costs of deconstruction is to follow the example of the City of Cotati. Before any demolition can take place, either public or private, the City requires the public to be acknowledged about the demolition project and the availability of potentially salvageable materials. Advertisement is accomplished through newspapers and written notices in the mail. This procedure save the contractor more money since the material is sold and reused which reduces the tipping fees [CIWMB 2006b].

Information about the limited amount of raw materials could encourage more contractors to choose deconstruction over demolition in order to preserve the environment. This concept follows the example set by the University of Texas. In the March 2002 issue of *Forest Products Journal*, it is stated that since the turn of the century 3,000,000,000,000 board feet (BF) of lumber has been produced in the United States [Ulrich 1990]. The NAHB estimated that 245,000 homes were destroyed through intentional demolition or disaster between 1980 and 1993 [Carliner 1996] and that the recovery of materials from these homes represented 2% of the 54.5 billion BF of softwood framing lumber consumed in the United States in 1999 [FALK 2002]. Seeing the potential of recycling and relating it to the environment can be used as an argument in the support of deconstruction. On average, 42% of raw materials are used by the building industry. Natural resources will not last forever and therefore by pointing out the potential for the recovery of materials, even if it appears to be small, would help reduce the amount of raw materials needed.

5 DECONSTRUCTION-RELATED TECHNOLOGIES FOR MATERIALS REUSE AND RECYCLING

There are several options available to recycle salvaged materials. Wood for example, can be recycled, reused, or incinerated. The USDA Forest Products Lab estimated that 80% of scrap wood was recovered in 1998 [AF&PA 2006]. According to the California Integrated Waste Management Board, one of the challenges with recycling is that some companies will only accept clean wood while others will take a mixture of waste wood [CIWMB 2006a]. The recovered wood is used to make mulch for gardens, animal bedding, playground cover, furniture, boiler fuel, fiberboard, and wooden pallets [AF&PA 2006]. Reusing wood requires little processing and there is currently a high demand for structural timbers. In addition, this option allows some diversion away from the landfills and expands the life of wood fiber supply [KIBERT 2006, AF &PA 2006]. The main challenge associated with this process is the lack of grading standards for recovered wood and therefore the salvaged wood can only be utilized on small projects. Incineration represents another alternative to dealing with wood waste. However, there are restrictions on the wood: it cannot be treated, painted, stained or contaminated with vinyl or nails [EWALL 2000]. Since it is difficult to verify these limitations, the impacts on the environment cannot be completely defined.

Other recovered debris includes drywall. One possibility is to recycle them by using grinders and screens. In that case, the recovered material can be used "to manufacture new drywall, in cement production, as a soil amendment or plant nutrient, in the manufacture of fertilizer, an amendment to composting systems, and for animal bedding" [CIWMB 2006c]. However, low landfill disposal fees represent a barrier to recycling drywalls. Looking at the environmental impacts, if sent to the landfills, hydrogen sulfide gas can be produced, especially in wet weather, and this would contaminate the soil. In addition, incineration cannot be considered as a strongly recommended option because of the potential production of toxic sulfur dioxide gas. This procedure is not allowed in California [CIWMB 2006c].

Other recyclable materials include steel, concrete, aggregate, bricks, shingles, and carpet. As far as steel, it is the most recycled material. Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) use steel scraps as a source for the production of new steel. According to the Steel Recycling Institute, the production of steel from BOF and EAF respectively, contain 32% and 96% of the recycled content [MCA 2004]. Recovered concrete is usually crushed and used as small aggregates in asphalt and new concrete [KIBERT et al. 2006]. Crushed concrete can be used as aggregate base or aggregate subbase, shoulders, gravel, roads as surfacing, base for building foundations, and fill for utility trenches [CIWMB 2006c]. Old bricks are reused and appreciated for their antique look. However, studies are currently being conducted to see if crushed bricks can be used as road base [KIBERT et al. 2006]. The market for recycled shingles is currently growing. By using a process of grinding and sieving, crushed shingles can be used as asphalt pavement, aggregate base and subbase, cold patch for pot holes, sidewalks, utility cuts, driveways, ramps, bridges, parking lots, road and ground cover, new roofing, and fuel oil [CIWMB 2006c]. One of the setbacks for this option is that old plants might not be equipped with the proper technology and some states might require some special permits. Finally, the market for salvaged carpet is limited, but eventually carpets can be recycled and used to produce carpet cushion, commercial nylon fiber with recycled content, construction sheeting, engineering resins, carpet tiles, resilient floor tiles, building insulation, asphalt pavements, and portland cement concrete [KIBERT 2006, MOEA 2005, CIWMB 2006c].

6 ANALYSIS OF COMMON C&D MATERIALS FOR REUSE AND RECYCLING

C&D waste materials are investigated in this paper to develop a sense of their sustainability options. A comprehensive table is created to address many important issues such as cost, recyclability and reusability. Fore each material, resulting from C&D waste out of an average house, the following issues have been addressed:

– The quantity present in buildings (or waste percentage)
– Cost of acquiring new (per sf, cy, linear foot, etc.)
– Reuse-ability (how, and into what materials if any change)
– Recycle-ability (how, and into what materials if any change)
– Cost and benefit of use
– Cost and benefit of recycling
– Embedded energy
– Landfill-ability
– Impact on environment
– New market for the underlying material
– Alternative materials

In Table 3, a quantitative analysis is launched to obtain the average quantity of materials for a typical residential house of approximately 2000 square feet. Only representative aspects of the underlying materials were addressed in Table 3. The amount of wood per residential housing is based upon the assumption that the building is typical wood framed house in North America. This quantity includes the wood frame, cross members, rafters, trusses and wood flooring. The average quantity of steel, per building, is based upon the same assumption of a typical wood framed home. This includes the weight of an average number of nails used in construction, the use of steel brackets for member connections, steel used in window installations, and steel piping for water and ventilation. The quantity of PVC piping per home is based largely on yard size for the home. It assumes that the average yard size for a residential home in the suburbs is approximately 1500 square feet. The piping will run from one point on the house and run two separate lines into separate areas of the yard. The amount of ceramic tile per household is based on the assumption that only the kitchen and bathroom floors will be covered with tile. The square footage of tile is based on the combination of average kitchen and bath sizes for a 2000 square foot home. The average square footage of concrete is a summation of the concrete used for the foundation of the building, some exterior concrete porch leading up to the house, and the driveway and garage of the home. The quantity of bricks per building is based on the assumption that the house will have the frontal face of a house partially covered with brick façade. This quantity also assumes that the house will have exterior planters made of brick. Asbestos, which is now considered a hazardous material, is a common material still present in houses today. This quantity assumes that all ceiling for the home may have been constructed with an asbestos layer. All other materials have not been quantified due to the immeasurable fluctuations in quantity.

In Table 3, the information presented shows the base cost of purchasing new construction material. This cost does not include transportation or cost of labor. The cost of new wood was measured per square foot. This is the cost of wood to construct a square foot of wall. This includes the studs and top and bottom plates. The cost of steel per ton was noted as the average price of steel in January 2006. The average costs of the rest of the materials were taken from data from 2005. Asbestos is an exception because it is no longer sold so a value of $0 was given to this material.

7 NVESTIGATION OF EXISTING AND INNOVATIVE TECHNOLOGIES FOR PROCESSING C&D WASTE

To further understand the technologies that can be used to process C&D waste, a list has been developed as shown in Table 4, illustrating available technologies that are suitable for certain types of C&D waste. The processing type (reuse, conversion, upgrading, downgrading, etc) is illustrated for technologies in Table 4. For each technology, the process type has been identified and described along with a general estimate of the cost for acquiring the technology.

Table 3. Deconstruction material characteristics

Type Of Material	Quantity Per Building	Cost (New)	Reuse-ability	Recycle-ability	Cost and Benefit of Reuse
Wood	13000 BF	$2.37 per sf	75%	85%	$40/ton
Steel	500 lbs	$500 per ton	100%	100%	
PVC	700 ft	$0.41 per lb	Not immediate	100%	
Ceramic Tile	100 sf	$300 - $500 per sf	Very low (0%)	Very Low Not immediate	
Concrete	3000 sf	$25-$42 per cy	Very low (0%)	100%	
Brick	1000 bricks	$23 per sf	35%	100%	
Asbestos	1500 sf	$0	0%	0%	N/A
Glass					
Gypsum			Half sheets & larger	95%	
Stucco				81.6%	
Appliances					
Plywood					
Fiberglass					
Linoleum					
Carpet					
Wallpaper					
Wood Shingles			0%	85%	
Aluminum Siding					

Type of Material	Cost Benefit	Embedded energy	Landfill-ability	Impact on the Environment	New Market for Material	Alternative Materials
Wood		1.2–4.6 MJ/Kg	High	Low	Yes	Steel
Steel	$11.25 per ton	10–34 MJ/Kg	Low	Low	Yes	Wood
PVC		70 MJ/Kg	Medium	Medium	Not Immediate	Copper Pipe
Ceramic Tile		2.5 MJ./Kg	Medium	Medium	No	Linoleum
Concrete		1–2 MJ/Kg	Low	High	Yes	Brick
Brick		2 MJ/Kg	Medium	High	Yes	Concrete, stucco
Asbestos	N/A		N/A	High	No	Textiles
Glass		15.9 MJ/Kg	Low		Yes	Plexiglas
Gypsum		4.5 MJ/Kg			Yes	Wood paneling
Stucco		1–2 MJ/Kg				
Appliances	N/A					
Plywood		10.4 MJ/Kg				
Fiberglass		30.3 MJ/Kg				
Linoleum		116 MJ/Kg				
Carpet		54–148 MJ/Kg				
Wallpaper		36.4 MJ/Kg				
Wood Shingles		9.0 MJ/Kg				
Aluminum Siding		191 MJ/Kg				

Most technologies are used for recycling and therefore their impact on the environment is addressed in Table 4. For example, bacteria can convert the sulfate in the gypsum to hydrogen sulfide (H2S) and other reduced sulfur compounds, which have a distinct odor.

Table 4. Deconstruction materials and type of technology

Materials	Type of Technology	Processing Type	Cost of Acquiring Technology	Efficiency of Technology	Impact of Technology on Environment	Market for this Technology	Applicability of Technology	Comments
Shingles	Recycling HMA-Hot Mixed Asphalt	Grinding & Sieving	Modifying equipment		Shingles may contain contaminants such as asbestos	Growing industry Products produced from recycled asphalt roofing shingles, asphalt pavement, aggregate base and subbase, cold patch, road and ground cover, new roofing and fuel oil	Older plants not equipped for this technology	Setting up a new concrete and asphalt recycling plant requires certain State and local permits, such as air and water and zoning.
Aggregate	Recycling	Crushing	A crushing plant may include a hopper, a jaw, a cone or impact crusher, a vibrating screen, and a rolling magnet			Primary market is aggregate base. Other markets include aggregate subbase, and shoulders in gravel roads as surfacing, as a base for building foundations and as fill for utility trenches		Setting up a new concrete and asphalt recycling plant requires certain State and local permits, such as air and water and zoning.

Wood	Recycled	Some request only clean wood that is untreated or unpainted while others will take a mixture of waste wood				The market for wood waste include use as feedstocks for engineered woods, landscape mulch, soil conditioner, animal bedding, compost additive, sewage sludge bulking medium, and boiler fuel		
Drywall	Recycling	Grinders & Screens		Drywall is mixed with other debris	Bacteria can convert the sulfate in the gypsum to hydrogen sulfide (H2S) and other reduced sulfur compounds, which have a fowl odor	Market includes manufacture of new drywall, use in cement production, as a soil amendment or plant nutrient, in the manufacture of fertilizer, an amendment to composting systems, and animal bedding	Low landfill disposal fees, and secondary market prevent growth	Sampling may be needed for lead and asbestos levels
Steel	Recycling	Oxygen furnace which uses a minimum of 25% steel scraps and/or a Electric Arc furnace which can be 100% steel scraps		Over 60% of steel produced is recycled	Saves energy and natural resources	Strong the “most recycled material”		Many states have mandates that require recycled steel to be used
Carpet	Re-use					Due to unfavorable market conditions there are limited opportunities for carpet recycling in the US and Component to produce other products such as auto parts, carpet pads, plastic lumber, and parking stops		

Market for this technology has been addressed to illustrate the future potential and the underlying technology (e.g., complex easy to use, high-tech, high skills, and labor intensive…) has been addressed. Table 4 demonstrates that a number of technologies can be identified for each type of C&D material. Still some technologies need further investment and research to make their way in converting C&D waste into useful products through reuse and recycling. [CIWMB 2006d, Texas DOT 2006, Virginia DOE 2002]

Many materials that can be salvaged today have a useful life cycle left in the economy of construction tomorrow. Whether it is recycling, reprocessing, or reusing materials, there is a growing or strong market for such commodities. With the application of technology changing for better efficiency, uses for these salvaged materials are increasing while offering more sustainable solutions.

Steel, for example, is one of the most recycled materials today. "All new steel products made from recycled steel can be recycled again at the end of their useful lives." Two types of processes are implemented, either an Oxygen furnace, which uses a minimum of 25% steel scraps; or an Electrical furnace, which uses up to 100% steel scraps. Steel scraps also have a use to make iron products, which contain approximately 75% of the recycled material. The process of recycling steel "…saves energy and natural resources. In a year, the steel industry saves the equivalent energy to power about 18 million households for a year." [Recycle 2006]

Wood is a material that can be processed, reused, or used as a feedstock for biomass fuel, mulch, and compost. For wood to be used for either, the industry requires the wood waste to be separated from other waste such as nails and fasteners. Processing for wood includes grinding or chipping for use as engineered woods such as particleboards, laminated woods, and plywood. If a member were to be used as a structural member, then the member would need to be recertified by a lumber inspector. The market for this material is limited because "the cost of processing and cleaning limits the economic viability of processing and reusing the material." [CIWMB 2006e]

Concrete and asphalt can be processed to reclaim aggregate. This type of process includes crushing the material using a jaw and/or impact crusher, and using a screen to sieve the aggregate. During the process, metal contaminates, such as rebar, can be removed by a rotating magnet. The market for this material is to use the crushed concrete as a bas, subbase, or shoulders for paved roads, gravel, base for building foundations, or as fill for utility trenches. "Currently the primary market is aggregate base and subbase in road projects." [CIWMB 2006e]

Shingles can be recycled and used for asphalt pavement, aggregate base and subbase, cold batch, new roofing and fuel oil. Before such processing, contaminants must be removed such as nails and wood. Processing includes grinding and may include sieving to conform to grading requirements. There is a concern with older shingles that may contain asbestos. Currently, there is a "limited amount of asphalt shingle recycling going on in North America." The reasons for this include resistance in the marketplace, lack of specifications, fear of hazardous contaminants, and governmental regulations. [CIWMB 2006e, Shingle 2006]

Used drywall can be recycled into new drywall only to a certain amount due to paper content. Other markets for drywall include agriculture, forestry, and land reclamation, nurseries, city parks, sod and compost. Contaminants for these materials include nails, tape joint compound and paint. Drywall with lead-based paint should be disposed of properly. The economic viability of this material depends on landfill tipping fees, cost of transportation, collection and processing, and the secondary market value. Traditional disposal methods of landfilling can cause odor problems and are toxic at high concentrations and when incineration is used it may produce toxic gases. [CIWMB 2006e]

Carpet can be recycled and used to make products such as auto parts, carpet pads, plastic lumber, and parking stops. However, there are constrained opportunities for carpet recycling in the US due to various adverse market conditions. [CIWMB 2006e]

8 COST SAVINGS

In an article of *The Future of Sustainable Construction* published in 2003, a case study showed that choosing deconstruction instead of demolition of the Presidio Building # 901 allowed a savings of $7,460. Overall, studies have shown that because of the revenues made from selling the used materials and savings made on landfill tipping fees, deconstruction becomes a cheaper alternative. [CHINI 2003] Table 5 compares demolition versus the deconstruction costs to show the potential savings that could occur due to reselling the recovered materials.

Table 5. Cost comparison at military and non-military installations

Location	Case Study	Deconstruction Cost ($)	Demolition Cost ($)	Reference	Website
Hampton	Fort Monroe deconstruction	Deconstruction allowed a $3,120 savings		HR Clean	www.hr.clean.org/Deconstruct.shtml
Wisconsin	Fort McCoy	Cost savings from salvage = $36,200		US Army Corps of Engineers	www.deconstructioninstitute.com/files/learn_center/27449035_LAM_RERE_FLM_post.pdf
San Francisco, CA	Presidio, Building # 901	9,340	16,800	Florida Center for Solid & Hazardous Waste	
Port of Oakland, CA	Building # 733	50,000	150,000	Florida Center for Solid & Hazardous Waste	
Baltimore County, MD	2000 sf residential building	9,000 – 11,000	7,000 – 11,000	Florida Center for Solid & Hazardous Waste	
N/A	2000 sf House	7,062 (after tax benefit)	10,100	The ReUse People	www.thereusepeople.org/Deconstruction
N/A	Flat in inner city	16,000	8,000	UC Berkeley, CA (done by a student)	http://greenyes.grrn.org/1999a/0790.html
California	Deconstruction of six homes	20,338	10,100	The ReUse People	www.jgpress.com/inbusiness/archives_free/000648.htm
Douglas, MA	Douglas school renovation	Recycling methods allowed a $31,812 savings (66%)		Recycling Construction & Demolition Wastes – A Guide for Architects & Contractors	www.agcmass.org/emplibrary/CD%20Recycling%20Guide%20Final%2004-05.pdf
Marlborough, MA	Boston Scientific Co.	Recycling methods allowed a $49,983 savings (63%)		Recycling Construction & Demolition Wastes – A Guide for Architects & Contractors	www.agcmass.org/emplibrary/CD%20Recycling%20Guide%20Final%2004-05.pdf
Hayward, CA	Hayward Reservoir	Cost savings from recycling = $12,000		Article in Construction & Demolition Recycling	www.allbusiness.com/periodicals/printArticle.asp?ID=430979
Richmond, VA	Demo of the Division of Consolidated Laboratory Services Bldg and the former Motor Fuel Lab	Cost savings from recycling = $490,000		Article in Construction & Demolition Recycling	www.allbusiness.com/periodicals/printArticle.asp?ID=23324
St. Paul, MN	Deconstruction of the US Army's Twin Cities Army Arsenal	Cost savings in transportation and tipping fees = $70,000		Lants and Falk, 1999, Article in Forest Products Journal (March 2002)	www.allbusiness.com/periodicals/printArticle.asp?ID=13328

According to the Portland Independent Media Center, deconstruction requires upfront funding but the benefits are seen in the form of tax deductions. [JONES 2005] [YOST 1998]

The Center for Construction and Environment at the University of Florida conducted a study on six houses during 1999 and 2000 to compare the costs between deconstruction and traditional demolition. The results are summarized in Table 6.

Table 6. Comparison between demolition and deconstruction costs

Costs	Demolition	Deconstruction	Deconstruction Savings	Additional Costs for Deconstruction as % of Total Demolition Costs
Labor	$1.74 (33%)	$3.64 (56%)	-$1.90	35%
Disposal	$2.17 (40%)	$0.97 (15%)	$1.20	-22%
Hazardous	$0.97 (18%)	$0.97 (15%)	$0.00	0%
Other	$0.48 (9%)	$0.89 (14%)	-$0.41	8%
Total	$5.36	$6.47	$-1.11	21%
Salvage	$0.00	$3.28 / $1.64	$3.28 / $1.65	61% / -31%
NET COSTS	$5.36	$3.19 / $4.83	$2.17 / $0.53	

Table 7 shows the deconstruction costs for Fort Monroe. Costs ranged from $6.28 to $9.75 per square foot, without accounting for asbestos removal and other disposal fees. Nearly 65% to 95% of the materials were recycled and reused during this project.

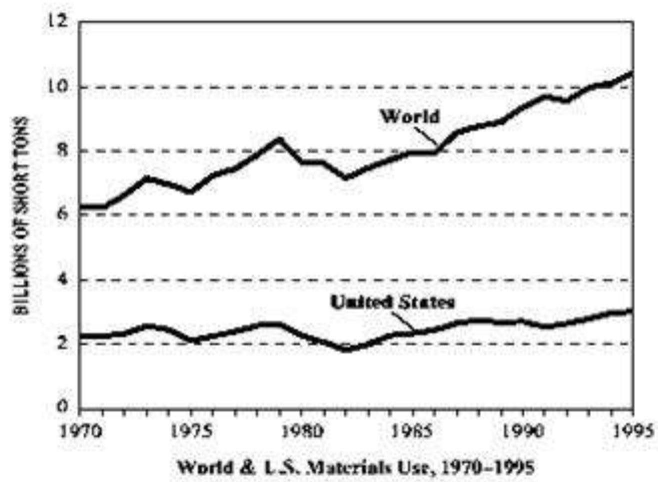
Table 7. Fort Monroe deconstruction Cost Summary

Building Type	Year Built	Square Footage	Costs*	% Reused / Recycled
Wooden frame	1941	2.239	$6.28	70%
Wooden frame	1941	4,830	$6.58	65%
Wooden frame	1941	4,830	$6.58	68%
Brick on wooden frame	1934	20,080	$8.41	76%
Masonry / hollow tile	1940	4,247	$8.84	85%
Masonry / hollow tile	1935	2,006	$9.35	93%
Masonry / hollow tile	1940	3,002	$9.72	95%

*Deconstruction costs per square foot, and do not include removal of asbestos-containing materials or other disposal fees.
Source: www.hrclean.org – 2/15/06
Note: The labor and equipment cost for deconstruction averaged $1.95 more per square foot than the estimated cost for conventional demolition. However, the disposal cost for material generated during conventional demolition (assuming 20% of the material was diverted from the landfill versus 75% achieved through deconstruction), would have averaged $1.13 more per square foot than deconstruction

9 THE C&D MATERIALS CLOSED LOOP

In this section, the goal is to understand the flow of materials during their life cycle from a systems approach perspective. Policies are enacted to make efficient use of materials that affect our economy, society and environment. The US Geological Survey (USGS) has studied the trend of materials life cycle by considering their impacts from the time of extraction to the possible end of their disposal. Figure 2 illustrates the materials flow cycle according to the USGS [USGS 1998].



Source: USGS Fact Sheet FS-068-09, June 1998 [USGS 1998]

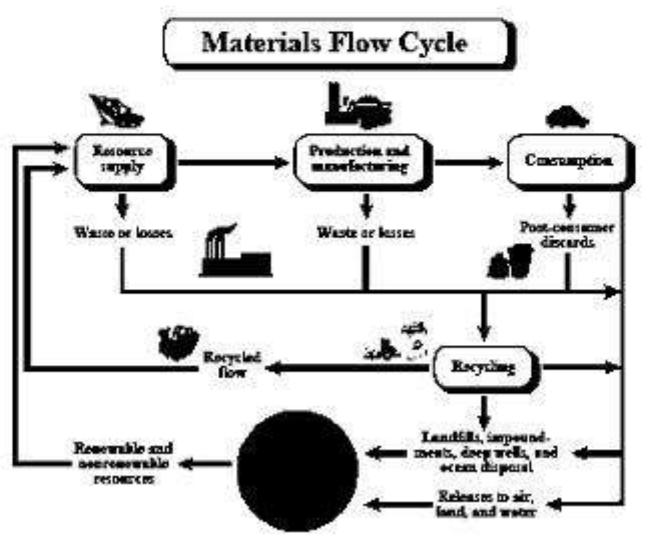


Figure 2. Overall material flow cycle

The USGS found a significant trend towards declining share of renewable resources such as construction materials. Since 1990, the demand of non-food, non-fuel construction materials, such as aggregate and sand, has jumped from 35% to about 60% according to the USGS [USGS 1998]. The consumption of raw materials between the turn of the 20th century and 1995 is shown in Figure 3.

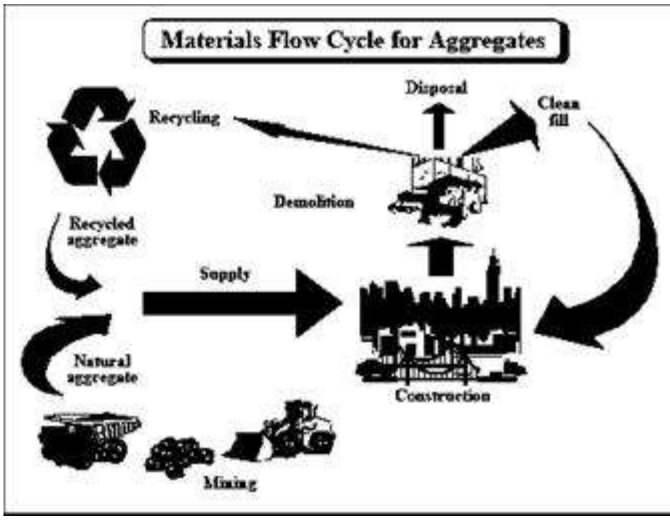


Figure 3. Aggregate material flow cycle

This figure reflects the enormous demand for construction (nonrenewable) materials over the past 50 years. It is also noteworthy to mention that between 1975 and 1995, non-food, non-fuel raw materials consumed in the US doubled over that period, and that consumption totaled one-third of the worlds total materials production according to the USGS [USGS 1998].

10 QUANTIFYING THE IMPACTS OF DECONSTRUCTION AND LANDFILL DIVERSION STRATEGIES ON SUSTAINABILITY (LAND, AIR AND SEA)

Deconstruction helps divert materials from landfill and incinerators, and also helps reduce our demand from natural products. It helps provide reusable materials to the construction and renovations industries, which in turn reduces our dependence on the environment.

The Institute for Local Self Reliance (ILSR) states that nearly 65 million tons of waste is produced every year from C&D activities. The data collected from a number of deconstruction projects proved that up to 45% of such waste could be diverted from landfills. Thirty-five percent of such recovered waste can be converted into reusable materials, and the rest can be recycled. Such practice of reusing and recycling helps minimize the amount of waste cluttering the landfill, reduce gas emissions from incinerators, and preserve and conserve natural virgin materials. The C&D industry has a long trend in consumption and dumping, and therefore it is time for sustainable practices. Deconstruction reduces our dependence on virgin materials and thus protects the environment by cleaning the air, ground, and water from litter that can be toxic or harmful in must cases. As a result, natural materials are conserved rather than used at a higher rate, and the energy needed to produce, transport, and use such materials is saved. [Mendler et al. 2000]

Deconstruction becomes an industry that produces low-cost materials that can be available for reuse and recycling. Production of new building materials is usually synonymous with pollution and contamination to earth, water, and air. This will certainly reduce the demand for manufacturing new materials that can cause significant damage to our environment. The operations of many mining and industrial establishments that produce building materials such as petroleum-based vinyl and PVC products are performed in or near low-income neighborhoods, which include large numbers of minorities.

Landfills and incinerators are notoriously known for their problems and long-term impacts on the environment. These processes would have lower impact when deconstruction diverts large quantities of C&D waste into a closed-loop system rather than disposal. It is known that the air will be cleaner when fewer amounts of C&D waste are disposed of. This will benefit low-income families and minorities who traditionally live in areas where these unwanted landfills and incinerators are built.

The presence of landfills and toxic waste disposal facilities impact and pollute the flow of water into the groundwater system. They also affect air quality because of the presence of harmful airborne substances. The best way to reduce these effects, besides using new technologies in processing waste, is to reduce the source of waste supplies through a total deconstruction strategy and to devise new technologies to handle waste. In many parts of the country and around the world, inappropriate disposal of materials subjects people to numerous environmental risks and health problems. (For additional information, please see ILSR website at http://ilsr.org/recycling/environmentalbenefits.htm)

11 TOOLS TO SUPPORT DECONSTRUCTION IMPLEMENTATION

A newly developed deconstruction-estimating model now exists designed to streamline the surveying of buildings for recoverable materials and evaluate the cost and feasibility of a deconstruction project. Developed for the US Army, this deconstruction assessment and estimating model is based upon data taken from actual deconstruction projects conducted on DoD sites. The model offers a wide array of user-friendly features and capabilities such as the ability to collect and upload field data from a personal digital assistant (PDA) and providing a highly portable method of gathering data during the survey of the candidate buildings.

In the coming years, existing military bases will be under continued pressure to remove thousands of surplus buildings in the most sustainable way possible, and deconstruction will increasingly become a logical alternative to demolition and landfill disposal. However, the practice of deconstruction continues to lag within DoD as the perception of higher cost, lengthier schedules, increased planning requirements, and greater safety liabilities remain within the minds of decision makers. A paradigm shift is likely to occur when these perceived hurdles are overcome and deconstruction becomes a more streamlined and cost-effective process.

A successful distribution and widespread use of this model will help to make material recovery and sustainable building removal methods more appealing to solid waste managers. Indeed, if it can evolve into a more viable and widely acceptable process, deconstruction could conceivably reduce C&D debris volume by 50% to 80% within DoD, significantly contributing to the department's overall sustainability goals.

Figures 4-6 below show various screenshots within the model.

Figure 4. Model opening page

Figure 5. Preliminary assessment page

Preliminary Economic Analysis

Demolition	
Estimated Building Demolition Cost [1]	$21,600
Non-Hazardous Waste Disposal [2]	$4,501
Contingency Cost (Assume 10%)	$2,610
Total Cost	**$28,711**
Deconstruction	
Deconstruction Cost (Labor) [3]	$24,576
Non-Hazardous Waste Disposal [2]	$2,063
Contingency Cost (Assume 10%)	$2,664
Potential Revenue from Salvaged Materials	**$7,173**
Total Cost	**$22,130**

Notes:
1. For this estimate, the demolition cost rate is $4.00 per square foot of building floor area (Selection of Methods for the Reduction, Reuse, and Recycling of Demolition Waste, Public Works Technical Bulletin 420-49-32, July 15, 2001).
2. Includes estimated hauling cost of $1.50 per cubic yard of debris (Napier et. al., Cost Analysis for Building Removal at Fort Chaffee, Arkansas, ERDC/CERL SR-01-15, June 2001).
3. Deconstruction labor rates are based on findings from Guy et. al., Fort Campbell Deconstruction Analysis, UF, December 2002. The labor hour estimate represents the removal of the total material quantities inputted into the building survey and does not account for the inputted percentage of salvageable materials.

Deconstruction Estimated Labor Hours and Potential Revenue

Building Component	Estimated Hours	Potential Revenue
Foundation		
Brick Chimney	11	$760
Exterior Wall Structure	41	$278
Exterior Wall Finish	138	$105
Partition Wall Structure	124	$96
Interior Wall Finish	210	$0
Ceiling Finish	86	$437
Roof Structure	399	$795
Roofing Material	65	$0
Floor Structure	311	$1,013
Floor Finish	540	$979
Windows and Doors	44	$1,250
Kitchen and Bathroom Fixtures	9	$75
Stairs	6	$102
MEP	9	$1,220
Other	-	$63
Total	**1,994**	**$7,173**

Notes:
(-) Data for deconstruction labor rates are unavailable.

Figure 6. Economic analysis page

12 CONCLUSIONS

Through the data presented in this paper and via the various comparative analyses conducted for materials reused and recycled, it is evident that deconstruction when planned properly will help lead to a sustainable future. The list of building materials that are recyclable is expanding everyday. Many energy-efficient building materials or "green materials" can be recovered and recycled as a result of deconstruction projects. Products ranging from roofing appliances and insulation, to landscaping products can all be recycled. The quality of information about potential buildings that are destined for deconstruction and/or demolition is vital. A survey conducted by the University of Sheffield in England with demolition experts who are members of the Federation of Demolition Contractors (NFDC) and other consultants in the business; shows that the trend is towards a likelihood of banning the disposal of recyclable materials in England, following a model of waste minimization program that was adopted by Netherlands. Based on expert testimony, the survey also suggests that records of all changes to a building be maintained with a clear identification of potentially hazardous materials noted on the drawings [McGrath et al. 2000].

Reasonable diversion rates of C&D waste from landfills are becoming more within reach than ever before. This has indeed proven beneficial and economic. Such goals are achievable in spite of high tipping fees and stricter dumping regulations. With the evolution of new technologies and the emerging market for many new recycled/remanufactured materials, diversion rates that lead to conserving valuable landfill space seem at all time high levels. Many contractors are exceeding their diversion rate goals while making money at the same time. C&D recycling companies in many states such as Pennsylvania, Florida, and California for example, are finding a large number of markets for their C&D waste for almost every type of material such as wood, plastics, paper, foam, bricks, glass, gypsum, insulation, carpet, concrete, steel, etc.

The table presented in this paper provides clear evidence that for a large number of material types, the cost/benefit of recycling, embedded energy, landfill-ability, impact on the environment, new market for such materials and their substitutes, can be quantified and described.

This paper exhibits a number of representative technologies that can help in the recycling and processing of C&D waste, and to yield a new, whether upgraded or downgraded material, that can be injected back in the market for raw materials for the construction industry. Each technology process can be applicable under certain conditions and its cost and energy needs may vary widely, which may affect its viability. In the case of processing steel, drywall, and shingles for different uses as illustrated in the paper, there are various environmental impacts that may determine the sustainability of such technologies as explained above.

Case studies from around the nation have shown the cost saving from practicing innovative deconstruction practices, which generally refers to their sustainability. It is evident from a study that deconstruction practices, if associated with the appropriate recycling technologies/processes, creative material reuse practices, and sound environmental planning, would lead to increasing landfill diversion of C&D waste. This indeed has proven to have great impacts on our demand for virgin materials, energy production, processed materials, and those that end up in the landfill, which are becoming a small proportion.

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SOURCES FOR DATA FOR MILITARY INSTALLATIONS

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Matherifield, California: http://www.ciwmb.ca.gov/Publications/ConDemo/43301027.pdf
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