Deconstructing Deconstruction: Is a Ton of Material Worth a Ton of Work?

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Abstract

In the summer of 2012 Williams College (Williamstown, MA) deconstructed two small wood-frame buildings and in the process, recycled 92 percent by weight of the total material removed from the project site. This report explores the greenhouse-gas emissions benefit of reusing and recycling the building materials using the EPA's Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks *and the EPA's Waste Reduction Model (WARM). This approach to building deconstruction resulted in emissions savings of 66 metric tonnes.*

Introduction

In the summer of 2012, Williams College deconstructed two smal wood-frame buildings. In a significant departure from traditional demolition work, approximately 92 percent, by weight, of the total material removed from the project site was recycled, salvaged, or otherwise diverted from a landfill or incinerator.

While green building advocates and green building certification programs encourage high levels of recycling and reuse, the benefits of such programs can be difficult to assess. Builders, developers, and environmentalists alike question whether the environmental benefit is sufficient to justify the extra time and cost of the deconstruction process.

This report attempts to quantify the avoided greenhouse-gas (GHG) emissions as one measure of environmental benefit achieved through the reuse and recycling of building materials. While other environmental benefits and externalities associated with resource production, consumption, and disposal are not included in this analysis, they are important environmental considerations in the life cycle of building materials. Effective recycling and reuse programs can help reduce, for example, landfill leachate that contaminates groundwater, and surface or air pollutants like particulates, NOx, dioxins, SO_2 and other by-products such as ash that are released by incinerators. Since only approximately 10 percent of estimated construction-related debris generation in New England was recovered for an end use outside a landfill in 2006, there is significant potential to improve the region's waste management practices.[1]

We begin our report by providing an overview of the building project; then we explain the emissions calculation methodology and describe the three project scenarios we used to evaluate the potential of greenhouse-gas emissions benefits. We also discuss the transportation implications associated with reuse and recycling. We conclude with a discussion of costs and a review of the lessons learned.

Building History

Seeley and Kellogg Houses are two of the oldest buildings on the Williams College campus. Seeley House was built in 1868 by the college carpenter and janitor, Robert R. Clark, using the old college paint shop as a starting point for his home. The history of this building is colorfully documented in "Stories of Old Williams College":

> For years the floors of the cottage were thickly splattered with blobs of hard dried paint, until new floors were built. He installed fine woodwork and a wooden ceiling in one of the bed-

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> rooms. Year after year he improved the house. The room over the South porch was notable, in a pleasant and sunny location …
>
> …An old carpenter shop which stood back of the Congregational Church was loaded on log runners and hauled down by six or seven yoke of oxen, and added to the east end of the former paint shop, for a wood shed and hen house.[2]

The building had been used intermittently as faculty or student housing and academic offices until it permanently closed in 2011.

Kellogg House was built in 1794 as the home for the Williams College president and was used for this purpose until 1858. Kellogg House was relocated and renovated in the 1870s and again in 1919. Its last occupants were the faculty and staff of the Center for Environmental Studies, from the late 1970s until 2008.

The long-planned expansion of the Sawyer Library encroached on the footprints of these buildings, so in 2011 Seeley House and the newer additions to Kellogg House were deconstructed. The historic 1794 portion of Kellogg House was temporarily relocated and will be renovated to provide office and learning space for the Center for Environmental Studies and the Zilkha Center for Environmental Initiatives—Williams' sustainability office.

To honor Williams College's commitment to minimizing its environmental impact, the project team chose to carefully deconstruct these buildings rather than employ traditional demolition processes to remove them, to recycle and reuse as much of the recovered building materials as possible, and to assess the environmental benefit of doing so.

Emissions Calculation Methodology

To calculate the GHG emissions associated with the on-site treatment, transportation, and processing of each material type recovered through the deconstruction process for this project, we used EPA's *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*[1] and the EPA's WARM. WARM was developed by the EPA to help small to moderate scale waste managers understand how their business-as-usual waste management practices compare to alternative practices.[3] WARM identifies five main processing options for material: source reduction, recycling, landfilling, combustion, and composting. In our calculations, we have used the emissions factors for source reduction as a proxy for the reuse processing option.

To determine the emissions impact of each of the material disposal strategies, we simply multiplied the appropriate emissions factor found in Table 1 by the amount (in tons) of recovered material. Emissions factors are provided by WARM in metric tonnes of carbon dioxide equivalent per short ton of material recovered ($MTCO_2E$/ton) for all the materials we required except for Mixed C&D (Construction and Demolition) Debris and Other (Table 1).

The category Other represents a small quantity—0.04% of the total weight—of material that was unclassified on-site. This category has not been included in the emissions calculations since an emissions factor could not be determined.

On the other hand, we calculated an emissions factor for the Mixed C&D Debris by determining the weighted average of the factors associated with material components of the debris. To do this, we assumed that the debris consisted of scraps of material from the other categories in proportion to the amount found on this project, excluding the category Other. The local C&D recycling facility reports a recycling rate of 80%[4] which we reduced by 20% to account for a presumably lower recovery rate since some of the recyclable materials would have already been separated from the debris on-site. Since emissions savings related to the C&D material account for only 5-10% (depending upon the scenario), we believe this assumption to be reasonable and not one to significantly affect the results. A complete analysis of the actual recycling recovery rates at C&D recycling facilities is beyond the scope of this report. Finally, we assumed that the remaining material would be disposed of at either a local waste-to-energy plant or landfill.

It is important to note that the calculated emissions savings/additions are meant to be compared to one another; they represent the effect of choosing one waste option over another rather than an

Table 1. WARM Emissions Factors by Material and Type of Processing

Material	Reuse ($MTCO_2E$/ton)	Recycle ($MTCO_2E$/ton)	Landfill ($MTCO_2E$/ton)	Combust ($MTCO_2E$/ton)
Steel	-3.706	-1.800	0.036	-1.548
Aluminum	-15.695	-13.616	0.036	0.045
Copper	-7.447	-4.977	0.036	0.041
Glass	-0.604	-0.282	0.036	0.039
Dimensional Lumber/ Clean Wood	-2.022	-2.458	-1.088	-0.450
Medium Density Fiberboard/Scrap Wood	-2.228	-2.473	-1.088	-0.450
Carpet	-4.017	-2.370	0.036	0.918
Concrete	N/A	-0.011	0.036	N/A
Asphalt Shingles	-0.202	-0.095	0.036	-0.339
Drywall	-0.217	0.029	0.124	N/A
Fiberglass Insulation	-0.500	N/A	0.036	N/A
Wood Flooring	-4.076	N/A	0.065	-0.587
Mixed C&D Debris	N/A	-0.571*	-0.319	-0.146
Other	N/A	N/A	N/A	N/A

*Mixed C&D Debris recycling factor (-0.571) calculated by the authors.

absolute value. Also, it must be noted that negative values indicate emissions savings and positive values indicate additions to emissions.

> WARM calculates and totals GHG emissions of baseline and alternative waste management practices—source reduction, recycling, combustion, composting, and landfilling. The model calculates emissions in metric tonnes of carbon equivalent (MTCE), metric tonnes of carbon dioxide equivalent ($MTCO_2E$), and energy units (million BTU) across a wide range of material types commonly found in municipal solid waste (MSW). … The WARM tool is based on a life-cycle approach, which reflects emissions and avoided emissions upstream and downstream from the point of use. As such, the emission factors provided in these tools provide an account of the net benefit of these actions to the environment.[5]

> Although emissions estimates provided by WARM are intended to support voluntary GHG measurement and reporting initiatives, WARM is intended as a planning tool and not an accounting tool. Its proper use entails comparing the current waste management practice with an alternative waste management practice and obtaining the impacts associated with changes in waste management practices.[6]

In all categories except for Dimensional Lumber/Clean Wood and Medium Density Fiberboard/Scrap Wood, reuse, as expected, results in lower greenhouse-gas emissions than recycling. The slightly higher emissions factor associated with reuse for this material category is explained by the EPA:

> This result is a function of the life-cycle framework that was used to estimate forest carbon sequestration. Estimates of forest carbon sequestration consist of two parts: 1.) impact on carbon in forests and 2.) impact on carbon stored in products. Both (reuse) and recycling result in increased forest carbon storage—both management practices reduce the amount of carbon that is harvested to make wood products. In terms of magnitude, (reuse) is slightly more beneficial. In terms of the product pool, recycling results in increased carbon storage, as recycled wood products are incorporated into new products. By definition, (reuse) does not result in a new product; therefore, no carbon is added to the product pool. The net effect of these two components of the forest carbon sequestration estimates is that recycling is more beneficial from a forest carbon sequestration standpoint than reuse.[4]

Transportation emissions were calculated for each material and disposal site pair based on the emissions factor provided by WARM of 0.0001404263 $MTCO_2E$ per ton mile and assumes a roundtrip. For the emissions resulting from the excavation of the foundation and deconstruction of the building, we estimated the hours of equipment operation for each scenario, which we multiplied by fuel efficiency (gallons of diesel per hour), values provided by the Federal Aviation Administration for various equipment types to determine the fuel consumption.[7] We then multiplied the fuel consumption by the emissions factor of 10.180 kg CO_2E per gallon of diesel.[8] The scenarios we analyzed are described in the next three sections. In all scenarios, the historic portion of Kellogg House was preserved and relocated. The Actual Story is what transpired and the other two scenarios are theoretical only.

Scenario 1: The Actual Story—Deconstructing Kellogg and Seeley

During the early weeks of the summer of 2011, EcoBuilding Bargains, a nonprofit, community-based environmental organization whose mission is to support the reuse of valuable materials and make home improvement affordable for more people,[9] carefully deconstructed the non-foundation portions of Seeley House and Kellogg House and sorted materials according to type and potential for resale, recycling, or other disposal option. A large forklift was the only heavy construction equipment used on-site for approximately 160 hours over the eight week process.

From the 7,000 square feet of buildings (2,500 square feet from Kellogg House, 36% of the total, and 4,500 square feet from Seeley House, 64%), 887.4 tons of material were recovered. As is typical, the densest materials, like concrete, made up the largest portion of the recovered materials: approximately 745 tonnes (83.9% of the total) was comprised of concrete or concrete masonry units (CMU). (See Table 2.)

Table 2. Materials Recovered during Deconstruction

Material Recovered	Weight (Tons)	% of Total Weight	% of Non-Foundation Weight
Aluminum	0.1	0.0%	0.1%
Fiberglass Insulation	0.2	0.0%	0.1%
Other	0.4	0.0%	0.3%
Copper	1.1	0.1%	0.8%
Glass	1.2	0.1%	0.8%
Wood Flooring	1.3	0.1%	0.9%
Carpet	1.4	0.2%	0.9%
Asphalt Shingles	3.8	0.4%	2.6%
Drywall	6.9	0.8%	4.8%
Steel	9.0	1.0%	6.3%
Medium Density Fiberboard/Scrap Wood	25.0	2.8%	17.5%
Mixed C&D Debris	45.3	5.1%	31.8%
Dimensional Lumber/Clean Wood	46.9	5.3%	32.9%
Concrete	744.9	83.9%	0.0%
Total	**887.4**	**100%**	**100%**
Non-Foundation	**142.5**	**16%**	
Foundation	**744.9**	**84%**	

Wood products accounted for the largest quantity—50.4%—of the non-foundational materials, followed by construction and demolition debris at 31.8%, steel 6.3%, drywall 4.8%, and shingles 2.6%. Overall, 92% of the building materials were recycled or reused (see Figure 1). Dimensional lumber and clean wood made up 77% of the reused materials (5.3% of the total materials). The concrete foundational materials accounted for 94% of recycled materials. Of the total materials recovered, 1% was disposed in a landfill and 7% incinerated at a waste-to-energy plant.

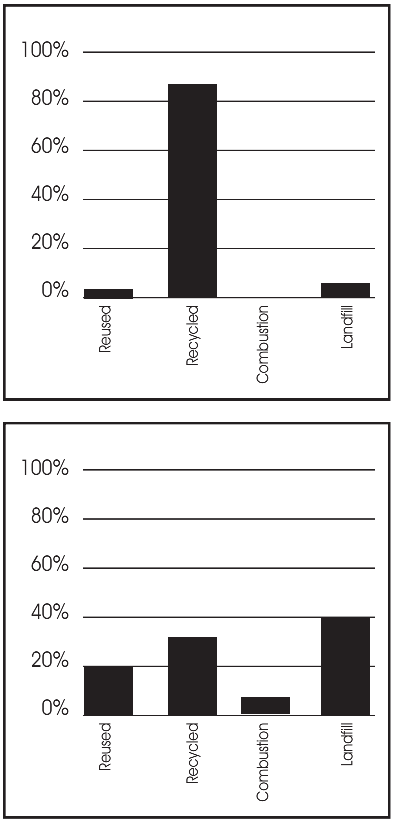


Figure 1. Percentage of Total Materials and Percentage of Non-Foundation Materials by Disposal Strategy

Of the non-foundational building components, 51% were reused or recycled while 41% of the building structure was landfilled. The landfilled materials were comprised of 78% mixed construction and demolition debris and 22% scrap wood. The remaining 7% of the building materials, primarily scrap wood, was incinerated. At the time of writing, it was unclear why 41% of the building structure was disposed in a landfill as it had been the intention of the project team to recycle 100% of the material, if at all possible. It is assumed this was due to contractor error.

A detailed analysis of the material disposal strategy is shown in Table 3. Most of the material that was slated to be reused was sent to EcoBuilding Bargains' warehouse and showroom in Springfield, MA, and will eventually be sold to contractors and builders who will use the items directly in building projects. These materials include steel, glass (windows), dimensional lumber/clean wood, carpet, fiberglass insulation, wood flooring, and other miscellaneous materials. A small portion of the dimensional lumber/clean wood was sent to Brattleboro, VT, where it will also be reused directly in building projects.

The materials that will be recycled include:

- steel: sent to North Adams, MA, for sorting and reprocessing
- aluminum and copper: sent to Springfield, MA, to be recycled with no loss of metal quality
- dimensional lumber and clean wood: unsuitable for reuse; will be converted into mulch in Montgomery, NY
- carpet: contaminated with mold and mud; sent to a facility in Framingham, MA, to be incorporated into a variety of products including composite lumber, tile backer board, roofing shingles, railroad ties, or carpet cushion
- concrete: hauled to Pownal, VT, for crushing and reprocessing into road base
- asphalt shingles: incorporated into new shingles, asphalt pavement, pothole patch, or road/ground cover in Wilbraham, MA
- drywall: delivered to Cambridge, MA, for reprocessing into new drywall

Since the deconstruction project was part of a larger deadline-driven construction project site, access issues, insurance requirements, and other constraints complicated the contractual arrangement among a number of service providers including the construction management firm, the deconstruction services provider, and the waste hauling companies. These complications inevitably led to miscommunication of project goals and intentions and inevitably suboptimal decisions related to material management and disposal.

At certain times during this project, contractors hauled material to a waste-to-energy plant or to a wood pellet production plant with the false understanding that these uses are considered "recycling." Moreover, certain material (such as the Mixed C&D debris) was hauled to a landfill when it could have been sorted and processed at a nearby recycling facility. Some carpeting was left unprotected outdoors, where it inevitably was soaked with rainwater and developed mold, thereby reducing its potential reuse/recycling value.

Not including the impact of the on-site work, a calculated 184.57 tonnes of greenhouse-gas emissions were avoided through the waste management processes, as shown in Table 4. Reused materials accounted for 32% of the emissions savings but only 3% of the weight. Together, recycling and reuse contributed 82% of the total emissions avoided and 92% of the waste by weight.

While the concrete foundation materials accounted for 84% of the weight of the recovered materials (see Figure 2), the emissions savings associated with recycling concrete contributed only 4% to the total. Metals (steel, copper, and aluminum) on the other hand, comprised 1.1% of the total weight but 15% of the emissions savings. Over half (57%) of the total emissions savings can be attributed to the reuse and recycling of the clean dimensional lumber that made up only 5% of the total weight!

While the heavy concrete components are often the greatest contributor to high recycling rates on construction projects, the most significant environmental benefit in terms of emissions reduction potential is derived through the reuse and recycling of other building materials, in this case, primarily the metal and wood products.

The equipment used on-site contributed 2.9 tonnes for the deconstruction of the above-ground structure and 3.2 tonnes for the excavation and removal of the concrete foundation materials, resulting in total emissions of 178.5 tonnes.

Table 3. Material Disposal Strategies and Weights

				Reuse			Recycle			Waste to Energy			Landfill		
Material	**Weight (Tons)**	**% of Total Weight**	**% of Non-Foundation Weight**	**Weight (Tons)**	**% of Total Weight**	**% of Non-Foundation Weight**	**Weight (Tons)**	**% of Total Weight**	**% of Non-Foundation Weight**	**Weight (Tons)**	**% of Total Weight**	**% of Non-Foundation Weight**	**Weight (Tons)**	**% of Total Weight**	**% of Non-Foundation Weight**
Aluminum	0.1	0%	0%	0.2	0.0%		0.1	0.0%	0.1%						
Fiberglass Insulation	0.2	0%	0%	0.4	0.0%	0.1%									
Other	0.4	0.04%	0%			0.3%									
Copper	1.1	0%	1%	1.2	0.1%		1.1	0.1%	0.8%						
Glass	1.2	0%	1%	1.3	0.1%	0.8%									
Wood Flooring	1.3	0%	1%	0.6	0.1%	0.9%									
Carpet	1.4	0%	1%			0.4%	0.7	0.1%	0.5%						
Asphalt Shingles	3.8	0%	3%				3.8	0.4%	2.6%						
Drywall	6.9	1%	5%				6.9	0.8%	4.8%						
Steel	9.0	1%	6%	2.5	0.3%	1.8%	6.5	0.7%	4.6%						
Medium Density Fiber-board/Scrap Wood	25.0	3%	18%							12.5	1.4%	8.8%	12.5	1.4%	8.8%
Mixed C&D Debris	45.3	5%	32%							0.0	0.0%	0.0%	45.3	5.1%	31.8%
Dimensional Lumber/ Clean Wood	46.9	5%	33%	20.7	2.3%	14.5%	26.2	3.0%	18.4%						
Concrete	744.9	84%					744.9	83.9%							
Total	**887.4**	**100%**		**26.8**	**3.0%**		**790.3**	**89.1%**		**12.5**	**1.4%**		**57.8**	**6.5%**	
Non-Foundation	**142.5**	**16%**	**100%**	**26.8**		**18.8%**	**45.3**		**31.8%**	**12.5**		**8.8%**	**57.8**		**40.6%**

Scenario 2: Base Case—Traditional Demolition

According to the EPA, the majority of C&D material ends up in two types of landfills: municipal solid waste landfills, which handle household waste; and C&D landfills, which are devoted exclusively to C&D materials. Unknown amounts of C&D materials are also believed to go to combustion facilities or unpermitted landfills.

In the base case scenario, we wanted to explore the implications of a traditional demolition program. We therefore assumed that the non-foundation portions of Kellogg and Seeley Houses would be demolished and sent to the nearest waste disposal site rather than being sorted and recycled.

Even with traditional demolition, high-value metals are often pulled from the construction debris or extracted from the building prior to the demolition, so we assumed that 90% of the building metals would be recovered for recycling. Since it is cheaper and more convenient to dispose of the concrete components at a reprocessing facility, we also assumed that the concrete components would be recycled in this manner, as has been the case at Williams for prior building demolition projects. The projected material processing and transportation-related emissions savings, total 118.79 tonnes, were attributable to the materials that were recycled (24%) and landfilled (76%). (See Table 5.)

We then added to this total the on-site work-related emissions for the excavation of the foundation and the building demolition. As calculated in the Actual Story scenario, 3.2 tonnes of emissions were generated by the foundation excavation. The on-site demolition of the above-ground structure requires five eight-hour days of work by an excavator operating at 80% capacity, based on estimates from Consigli Construction Company, Inc., with an estimated fuel usage rate of 9.45 gal/hr resulting in 3.1 tonnes of emissions. Therefore, the total emissions savings associated with the demolition is 112.5 tonnes.

Scenario 3: Maximum Reuse and Recycling

To test how much higher recycling and reuse rates might have been able to

Table 4. Actual Story—Material Processing and Transportation Emissions

	Weight	Processing/ Transport Emissions	Material Recovered	Processing/ Transport Emissions	Reuse Emissions	Recycle Emissions	Combustion Emissions	Landfill Emissions
Material	Tons	Tonnes	% of Total Weight	% of Total	Tonnes	Tonnes	Tonnes	Tonnes
Aluminum (recycled)	0.12	-1.63	0%	1%	0.00	-1.63	0.00	0.00
Fiberglass (reused)	0.15	-0.07	0%	0%	-0.07	0.00	0.00	0.00
Other	0.39							
Copper (recycled)	1.11	-5.51	0%	3%	0.00	-5.51	0.00	0.00
Glass (reused)	1.17	-0.69	0%	0%	-0.69	0.00	0.00	0.00
Wood Flooring (reused)	1.27	-5.18	0%	3%	-5.18	0.00	0.00	0.00
Carpet (recycled, reused)	1.35	-4.21	0%	2%	-2.49	-1.71	0.00	0.00
Asphalt Shingles (recycled)	3.77	-0.31	0%	0%	0.00	-0.31	0.00	0.00
Drywall (recycled)	6.90	0.35	1%	0%	0.00	0.35	0.00	0.00
Steel (reused, recycled)	9.04	-21.07	1%	11%	-9.37	-11.70	0.00	0.00
Scrap Wood (landfill)	25.00	-19.06	3%	10%	0.00	0.00	-5.59	-13.47
Mixed C&D (landfill)	45.30	-13.97	5%	8%	0.00	0.00	0.00	-13.97
Clean Wood (reused, recycled)	46.91	-105.57	5%	57%	-41.65	-63.93	0.00	0.00
Concrete (recycled)	744.93	-7.63	84%	4%	0.00	-7.63	0.00	0.00
Total	**887.40**	**-184.57**	**100%**	**100%**	**-59.46**	**-92.08**	**-5.59**	**-27.44**
% of Total Emissions					**0.32**	**0.50**	**0.03**	**0.15**
% of Total Weight					**0.03**	**0.89**	**0.01**	**0.07**

improve upon the emission rates of the demolition project, we developed the Maximum Reuse and Recycling scenario. In this scenario, we projected that a greater percentage of carpet and asphalt shingles would be reused, 80% and 50% respectively; the mixed C&D debris would be sent to a recycling facility for mechanical sorting and further processing; and the wood products would be recycled rather than reused. This scenario resulted in 248 tonnes of emissions savings (see Table 6).

In the Actual Story, the sorting of all recoverable materials was successfully completed on-site. The recycled material quantities were lower than those calculated for this scenario because materials were either damaged by weather or mistakenly delivered to the wrong processing facility. Therefore, we concluded that the emissions associated with the on-site excavation and demolition work would be similar to that of the Actual Story. The total emissions savings for this scenario is 241.9 tonnes.

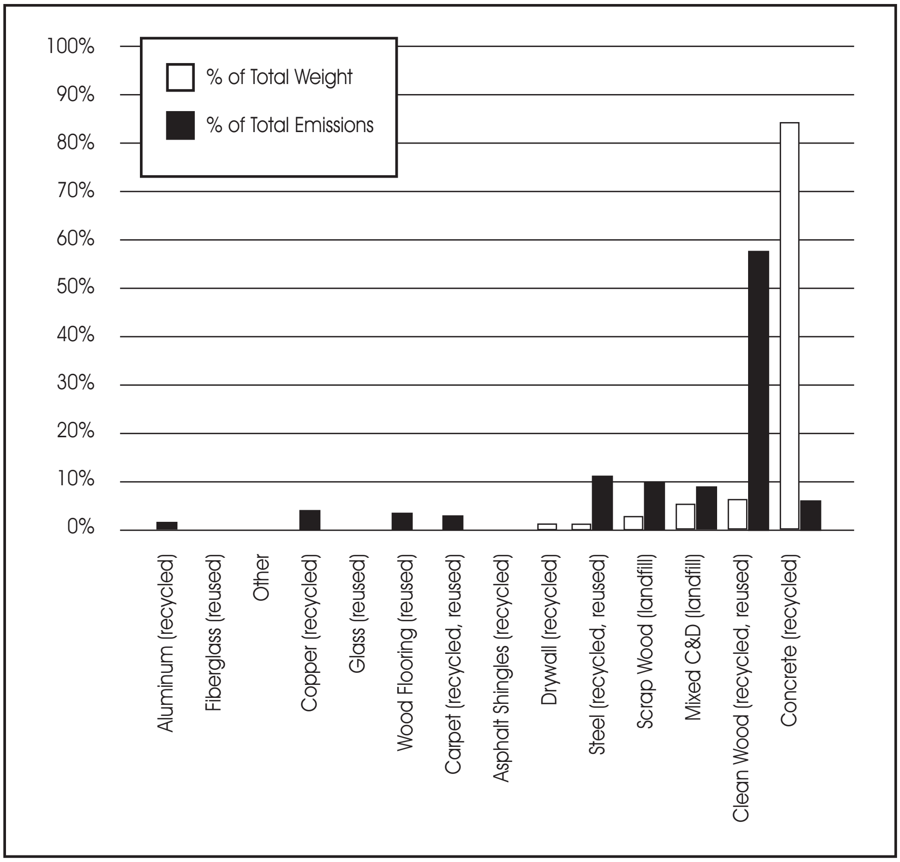


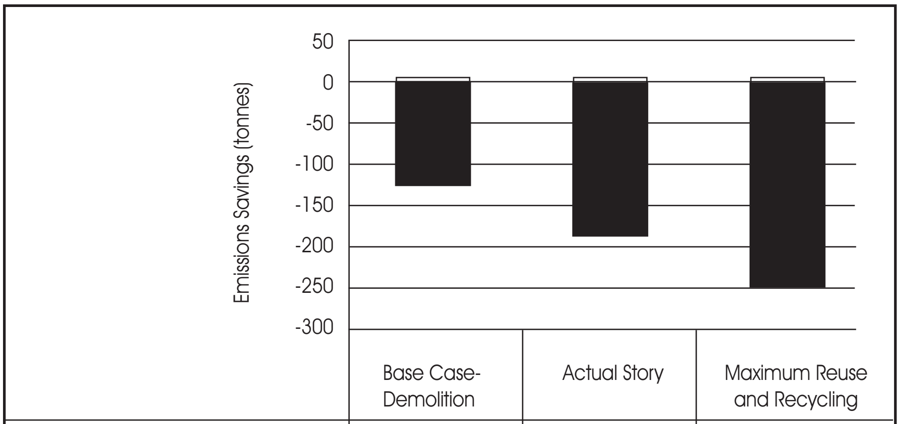
Figure 2. Material Weight and Emissions as Percent of Totals

Table 5. Base Case—Traditional Demolition Processing and Transportation Emissions

	Weight	Processing/ Transport Emissions	Material Recovered	Processing/ Transport Emissions	Reuse Emissions	Recycle Emissions	Combustion Emissions	Landfill Emissions
Material	Tons	Tonnes	% of Total	% of Total	Tonnes	Tonnes	Tonnes	Tonnes
Aluminum	0.12	-1.47	0%	1%	0.00	-1.47	0.00	0.00
Fiberglass	0.15	0.01	0%	0%	0.00	0.00	0.00	0.01
Other	0.39		0%	0%				
Copper	1.11	-4.96	0%	4%	0.00	-4.96	0.00	0.01
Glass	1.17	0.05	0%	0%	0.00	0.00	0.00	0.05
Wood Flooring	1.27	0.10	0%	0%	0.00	0.00	0.00	0.10
Carpet	1.35	0.06	0%	0%	0.00	0.00	0.00	0.06
Asphalt Shingles	3.77	0.18	0%	0%	0.00	0.00	0.00	0.18
Drywall	6.90	0.93	1%	-1%	0.00	0.00	0.00	0.93
Steel	9.04	-14.60	1%	12%	0.00	-14.64	0.00	0.04
Scrap Wood	25.00	-26.94	3%	23%	0.00	0.00	0.00	-26.94
Mixed C&D	45.30	-13.97	5%	12%	0.00	0.00	0.00	-13.97
Clean Wood	46.91	-50.55	5%	43%	0.00	0.00	0.00	-50.55
Concrete	744.93	-7.63	84%	6%	0.00	-7.63	0.00	0.00
Total	**887.40**	**-118.79**	**100%**	**100%**	**0.00**	**-28.70**	**0.00**	**-90.09**
% of Total Emissions					0%	24%	0%	76%
% of Total Weight						85%		**15%**

Table 6. Maximum Reuse and Recycling—Processing and Transportation Emissions

	Weight	Disposal Emissions	Reuse Emissions	Recycle Emissions	Combustion Emissions	Landfill Emissions	Maximize Reuse Recycling Assumptions
Material							
Aluminum	Tons	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes	
Fiberglass Insulation	0.12	-1.63	0.00	-1.63	0.00	0.00	
Other	0.15	-0.07	-0.07	0.00	0.00	0.00	
Copper	0.39	0.00	0.00	0.00	0.00	0.00	
Glass	1.11	-5.51	0.00	-5.51	0.00	0.00	
Wood Flooring	1.17	-0.69	-0.69	0.00	0.00	0.00	
Carpet	1.27	-5.18	-5.18	0.00	0.00	0.00	80% reused, compared to 46%
Asphalt Shingles	1.35	-4.97	-4.33	-0.64	0.00	0.00	50% reused, rather than recyled
Drywall	3.77	-0.52	-0.36	-0.16	0.00	0.00	
Steel	6.90	0.35	0.00	0.35	0.00	0.00	
Medium Density Fiberboard/	9.04	-21.07	-9.35	-11.71	0.00	0.00	100% recycled rather than combusted, landfilled
Scrap Wood	25.00	-61.47	0.00	-61.47	0.00	0.00	
Mixed C&D Debris	45.30	-25.20	0.00	-25.20	0.00	0.00	100% recycled rather than landfilled
Dimensional Lumber/ Clean Wood	46.91	-114.41	0.00	-114.41	0.00	0.00	100% recycled rather than reused
Concrete	744.93	-7.63	0.00	-7.63	0.00	0.00	
Total	887.40	-248.00	-19.99	-228.01	0.00	0.00	



	Base Case-Demolition	Actual Story	Maximum Reuse and Recycling
▨ Excavation of Foundation	3.2	3.2	3.2
□ Demolition/Deconstruction	3.1	2.9	2.9
□ Transportation	1.8	2.0	2.0
■ Material Processing/Disposal	-120.6	-186.6	-186.6

Figure 3. Relative Emissions Savings

Comparing the Results

Since the greenhouse-gas emissions savings and additions are relative to each other, we used the Base Case—Traditional Demolition (113 tonnes) as the benchmark. The Actual Story (179 tonnes) resulted in emissions savings of 66 tonnes and the Maximum Reuse and Recycling (242 tonnes) scenario would have saved an additional 63 tonnes (see Figure 3). Transportation and on-site-related emissions had only a minor impact on the end result.

In Figure 4, we see the relative benefit of emissions avoidance resulting from the scenarios. Recycling wood materials, reducing the amount of C&D landfilled, and recovering more steel produced the greatest improvement over the benchmark scenario. A small improvement was realized by avoiding the contamination of the carpet. Only in the case of the Medium Density Fiberboard and Scrap Wood category did the traditional waste management practice outperform the actual scenario in terms of emissions benefit.

The emissions savings resulting from the deconstruction came at a cost of $1,744/tonne for the actual scenario, and $889/tonne for the optimal case, based on estimates provided by Consigli Construction, Inc. (see Table 7). These emissions costs are higher than would be realized for a typical energy efficiency project where costs per tonne of emissions avoided over the lifetime of the project are generally less than $100, although they can vary widely.

On the other hand, other environmental benefits accrue from effective reuse and recycling programs that have not been included in this analysis, which considers only one environmental impact—the production of greenhouse gases. As mentioned earlier, these other environmental benefits are important considerations in the life-cycle analysis of building materials. Reducing the amount of material deposited in landfills can reduce leachate that contaminates groundwater, and avoiding waste-to-energy plants has the potential to reduce air pollutants like particulates, NOx, dioxins, SO_2 and other by-products, such as ash, which are released by these incinerators. Reducing the need for industrial production of materials can minimize the resource depletion as well as pollutants released to the environment during their manufacture.

By comparison, the cost of material disposal was approximately $56/ton of material for the base case and $186/ton for the other scenarios. While the recycling cost is over three times as much as the base case, it is about half the price of daily municipal solid-waste management and disposal at Williams College.

In addition to the greenhouse-gas emissions savings, this project contributed in some degree to the goals of the EPA's C&D Waste Reduction and Utilization program by characterizing, measuring, and

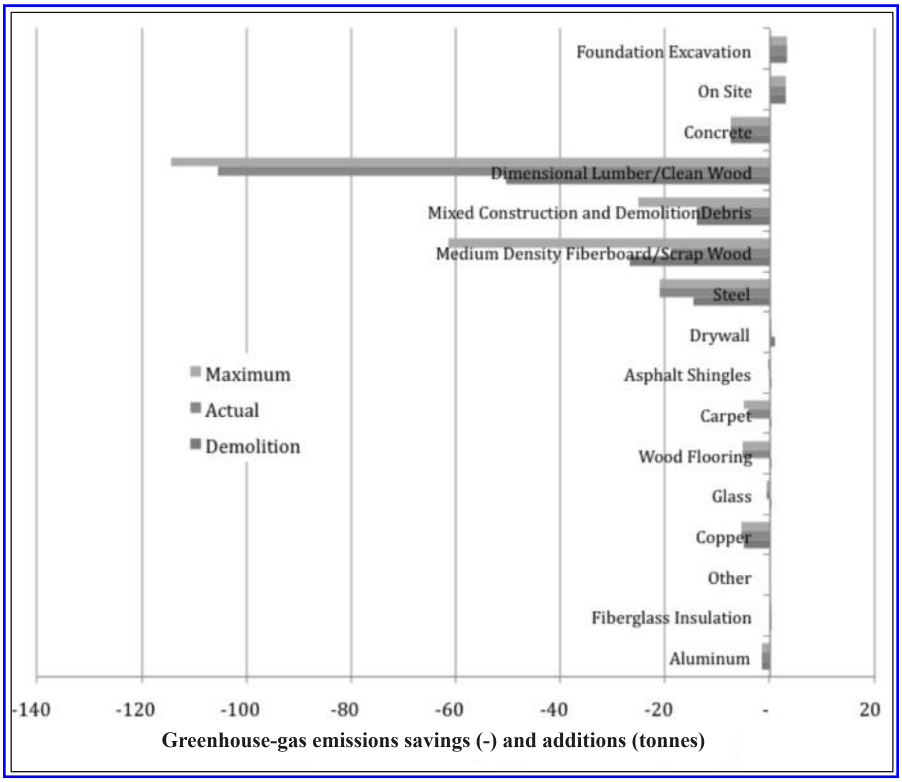


Figure 4. Relative Greenhouse-Gas Emissions Savings and Additions

Table 7. Project Costs

Costs	Demolition	Actual	Maximum
Foundation	$ 10,000	$ 10,000	$ 10,000
Deconstruction/Demolition	$ 40,000	$ 155,000	$ 155,000
Total	**$ 50,000**	**$ 165,000**	**$ 165,000**
Cost per tonne of emissions avoided		$ 1,744	$ 889
Cost per ton of material	$ 56	$ 186	$ 186

increasing knowledge and understanding of the C&D materials stream; promoting research and development of best practices for C&D materials reduction and recovery; fostering markets for construction materials and other recycled materials; and working with key players in the construction, remodeling, and demolition industries to implement more resource-efficient practices.[10]

Transportation

Project managers can be reluctant to transport materials long distances to recycling facilities due to the added cost and the presumption that the negative environmental impact of the transportation outweighs the benefits. In fact, we found that processing-related emissions savings are generally much greater than the emissions resulting from on-site work and transportation, particularly for metals, flooring, and wood products. Table 8 shows the number of miles necessary to offset the emissions savings impact of various disposal strategies, derived by dividing the emissions factor of the processing (in MTCO$_2$E/ton) by the emissions factor associated with transportation (in MTCO$_2$E/ton mile). Here, positive values indicate transportation miles necessary to offset the emissions savings.

Conclusion

Through the deconstruction effort, Williams College reduced the potential greenhouse-gas emissions associated with disposing of used building materials by 66 tonnes, yet failed to reach the estimated maximum potential savings (130 tonnes) due to a variety of on-site issues. While the cost of deconstruction was higher than typical demolition strategies, future projects may see a cost reduction as expertise and opportunities for recycling increase.

Table 8. Transportation Distance to Offset Emissions Savings of One Ton of Material

	Reuse (Miles)	**Recycle** (Miles)	**Landfill** (Miles)	**Combustion** (Miles)
Aluminum	111,763	96,961	-256	-320
Copper	53,028	35,443	-256	-293
Wood Flooring	29,023		-465	4,183
Carpet	28,604	16,877	-256	-6,536
Steel Cans	26,391	12,821	-256	11,025
Medium-Density Fiberboard*	15,865	17,614	7,749	3,203
Dimensional Lumber*	14,399	17,503	7,749	3,203
Glass	4,304	2,006	-256	-276
Fiberglass Insulation	3,561		-256	
Drywall	1,547	-205	-881	
Asphalt Shingles	1,439	674	-256	2,416
Mixed C&D*		4,066	2,272	1,040
Concrete		76	-256	

* Wood products disposed in landfills continue to act as carbon sinks. While it is beneficial from a carbon management perspective to dispose of used wood products in landfills compared to incineration, greater carbon benefits are achieved through recycling or reuse.

Clearly, reusing and recycling metal (aluminum, steel, copper) result in the greatest emissions savings per ton of material. Efforts should be made on demolition and deconstruction projects to recover as much of these materials as possible. Concrete and similar projects often contribute significant volumes to the calculation of percentage of building materials recycled for green-building certification but the benefit in terms of greenhouse-gas emissions is comparatively low. Somewhat surprisingly, greater carbon savings can be earned through recycling of wood products rather than reusing them, as recycling results in increased carbon storage when recycled wood products are incorporated into new products.

Transportation related emissions for many materials were insignificant. With the exception of concrete materials and drywall recycling, materials can be shipped long distances before transportation-related emissions offset the environmental benefit.

Developing a deconstruction plan that targets the materials with the most significant environmental impact, that ensures protection of the materials from the weather, and that provides clear instructions for the hauling contractors should produce a material disposition strategy having the greatest benefit at the least cost.

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A worker prepares wood for recycling.

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Author Disclosure Statement

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