Building Deconstruction in New Haven, Connecticut
A Systems Dynamics Analysis and Policy Tool

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Introduction

Solid waste generated in the removal or renovation of buildings is a massive and often poorly described waste stream. Construction and demolition waste (C&D) is also largely unregulated in its quantity and composition, if not its disposal fate. Buildings are large, complex, and highly varied objects, and their component materials differ by building type, construction cohort, size, style, and many, many other factors. Reducing the solid waste generated in building removal and renovation, recouping building material for reuse or recycling, preventing some of the greenhouse gas emissions associated with C&D disposal, shifting jobs towards construction laborers, and reducing costs are all goals of deconstruction, a source separation building removal technique.

Deconstruction of buildings and the potential it creates for material recovery is described at length elsewhere (Carter, 2010; Roussat et al., 2009; Seldman, 2009; Boone, et al., 2008; Shami, 2008; USACE, 2007; Schultmann and Nicole, 2007; Shami, 2006; Knapp, 2006; Roper, 2006; Toto, 2005; Lennon, 2005; Greer, 2004; Falk, 2002). Deconstruction is the dismantling of buildings by hand or by a combination of mechanized and manual means with the intention of reusing or recycling the materials generated in the process when possible. Demolition is the removal of a building, most often by mechanized means, in which all materials are crushed and disposed of in a landfill. Here we ask what the quantitative environmental and economic potential of deconstruction is for the small northeastern city of New Haven, Connecticut. Utilizing a dynamic systems model of construction material flows in New Haven we can estimate what is largely an uncounted waste stream, determine whether deconstruction techniques and downstream reuse and recycling of building materials provide a stop gap or a solution to the runaway generation of C&D, test C&D materials management plan options currently on the table in the City, and evaluate the environmental and economic strengths and weaknesses of these plans. Without such a planning tool, policy makers and regulators in northeast cities like New Haven are faced with the promises of deconstruction but are blind as to the potential costs and benefits requiring use of this technique might have.

As of this writing, there are two companies performing full or partial deconstructions of houses in the New Haven area, and the first record of a fully deconstructed building in New Haven is described in the case study below. City officials in the Office of Economic Development view deconstruction as a potential source of job creation in the city and efforts to grow the market for reused products and deconstruction services are supported by city environmental officials (Snyder, 2010a).

While much of the data for this study came from generic building materials calculators for volume and mass and from the literature, results were compared to the case study house to confirm accuracy. As the case study is the first recorded deconstruction in New Haven, the particularities of that project introduce uncertainty into the accuracy of comparisons with the results generated here and should be viewed with caution.

Previous studies and other authors have focused on the promise of deconstruction largely for residential structures (Denhart, 2010; Quinn, 2008; Shami, 2006; Dong, et al., 2005; Dantata, et al., 2005; Falk, 2002) though there are notable exceptions (Roper, 2006, e.g.). Others have focused on the potential hazards of materials generated from older buildings and containing lead and asbestos, considering new methods for isolating or neutralizing such toxins in productive applications (Hu, et al., 2010). Several case study buildings that have been successfully deconstructed demonstrate that as much as 95% of building material can be salvaged for reuse or recycling, some or all of the removal costs can be saved or recouped, and several deconstruction jobs can be created where only one or a few demolition jobs once existed (Bauman, 2010; Roussat, et al., 2009; Munroe, et al., 2006; Shami, 2006; Roper, 2006; Dantata, et al., 2005; Schultmann and Otto, 2002).

Far fewer studies attempt to address the impacts of deconstruction across several structures, whole cities, or regions (Couto and Armando, 2010). One such study (Dentata, et al. 2005) considers the potential for deconstruction methods to address recent C&D waste bans in the state of Massachusetts but produces results that are not aggregated up to the entire construction and demolition system (as they are presented on a per square foot basis) or beyond residential buildings to consider large scale impacts.

Two studies focus on the potential for deconstruction to provide materials for disaster relief, and deconstruction as a building material source for some developing regions has been discussed elsewhere (Reiff, 2010a). Both from an empirical point of view and from a systems modeling point of view, deconstruction is a valid alternative to demolition in rebuilding disaster areas such as New Orleans after Hurricane Katrina (Denhart, 2010; Quinn, 2008). But what of gradual deconstruction under ordinary construction and demolition circumstances?

Some authors speak of design for deconstruction and closed loop building materials cycles in hypothetical and ideal situations (Sassi, 2008; Debacker, et al., 2007; Gorgolewski, 2006; Webster and Costello, 2005). These are valid goals for future builders and designers, but are they possible today, given the building stock that is currently being removed? How much material can be reclaimed from an urban area containing buildings that age from brand new to over 200 years old? What amount of material must be landfilled, what can be recycled and what reused given existing facilities for downstream management? Is a closed loop building materials system possible in New Haven today or is something more modest a more likely reality?

Previous modeling studies show divergent answers to some of these questions, chiefly because of assumptions about the type and percentage of material that can be reused (Roussat, et al., 2009; Quinn, 2008). Here we recommend and employ, as discussed below, a method that evaluates the questions above assuming the current scale and capability of waste management facilities in New Haven today. This method provides an extremely limited view of possibilities, but one that attempts not to err too far on either the side of caution or optimism.

For this modeling approach we must consider sources and documentation for building types and lifetimes (LiVES, 2010; Ruhrberg, 2006) disparate economic situations (Munroe, 2006), upstream environmental impacts of removal processes (Schultmann, 2007; Thormark, 2006), and downstream environmental impacts of landfilling, reuse, and recycling of building materials. Of particular importance is consideration of the lifecycle of building materials and the attribution of embodied energy and emissions either to projects from which materials are removed or to new construction projects (Lippke, et al., 2004). Here we employ the EPA WARM model (EPA, 2009), discussed below, as a general guide to emissions from a waste management perspective, though it is clear from other studies that much higher levels of specificity can be achieved in quantifying embodied energy and resulting emissions by tracking such information using full lifecycle analysis tools on actual individual projects rather than estimates for future projects at the level of a city (Chong and Hermreck, 2010). Future work should seek to improve upon the specificity detailed here.

In the expanding, changing realm of deconstruction literature, and especially as it concerns the northeastern United States, it is time to move beyond the individual house, the single building type, and general estimates of the mass of construction materials generated and the costs of deconstruction. This study is one of a growing number that seeks to address materials flows and management options from the scale of each building material type, up to the whole building, and further up to the range of buildings in an entire city. Recognizing that all buildings are not created equal and removal costs depend not only on method but also on highly specific circumstances, an attempt is made here to also provide a top-down view of an urban material system.

Case Study

During the month of June, 2010, the New Haven Regional Contractors' Alliance, with support from the Workforce Alliance and the City of New Haven Office of Economic and Business Development, deconstructed a one hundred year old house in preparation for the construction of a multi-unit mixed income housing development on the same site. The deconstruction project was also used as a training experience for twelve local contractors to provide the skills and expertise necessary to incorporate deconstruction practices into their current building, remodeling, and demolition jobs.

New Haven, CT Pilot Deconstruction Training Program

The home deconstructed during the Contractors' Alliance training not only was over a century old but had been abandoned for two years at the time of removal. The challenges presented in such a project included commonplace concerns such as lead and asbestos abatement and non-standard historical building practices in an urban area with old housing stock such as New Haven. Unique concerns presented by the house's abandonment will become more commonplace as the City of New Haven increases its effort to remove such blighted homes from the community.

Costs

Despite the above concerns, the cost of completing the deconstruction was lower than the lowest estimates to demolish the building, provided more jobs for the community, and resulted in approximately 30% of materials being diverted from landfill for reuse or recycling. The environmental benefits of diverting material from landfill, including shorter transportation distances, are compounded by the reuse of that material in new construction projects, thus offsetting embodied energy and other production impacts of building with virgin material.

The costs of deconstructing the twelve hundred square foot home included the following expenses: a pre-demolition survey of accessible lead and asbestos; removal of asbestos containing siding and flooring by certified professionals; disconnecting water, sewer, electrical, gas, cable, and phone lines; transport and rental of roll-off containers for recyclable material and waste; tipping fees; rental of on site storage container; truck rentals for transporting material for reuse; backfilling the foundation hole; and a six person labor crew. The cost estimates for demolishing the house, provided in bids from three separate local demolition contractors, included all of the above except: a pre-demolition survey of accessible lead and asbestos; disconnecting utilities; transport and rental of roll-off containers for recyclable material and tipping fees; rental of on site storage container; truck rentals for transporting materials for reuse; and a six person labor crew – one or two workers are required for a demolition of this size.

The three demolition bids came in between $19,000 and $24,000. The cost of deconstructing the house, not including those items omitted from the demolition bids or the cost of asbestos abatement was $11,800. Including asbestos abatement and backfilling of the foundation hole brought the cost of deconstruction up to $17,000 – less than the lowest demolition bid. The reusable materials generated during deconstruction were donated, and because this was a city project, no tax benefits resulted from the donation and no resale value was recouped. Therefore, this cost total would have been lower had this been a private project.

All houses, especially older houses, are different and costs for deconstruction versus demolition will vary significantly. Not all old houses contain asbestos, for example. Similarly, while this particular project included the cost of backfilling the foundation hole, this was due to the fact that the same building footprint will not be used for the future construction project. In most cases, homes are deconstructed with the express purpose of constructing a new home on the same location, thus eliminating this expense.

Diversion

Diversion from landfill in the State of Connecticut is defined as the reuse or recycling of waste materials but not the burning of waste materials at a waste-to-energy facility. Diversion is calculated as a percentage by weight.

Typically, up to half the weight of a house such as that deconstructed in this pilot program is in the foundation. Foundation material is often diverted from landfill by crushing and reuse as clean fill. In this instance, because the foundation hole was not to be reused, the stone foundation was backfilled into the foundation hole as clean fill. By the standards established by the Connecticut Department of Environmental Protection, this does not constitute diversion from landfill. The diversion rate for this pilot project was approximately 30%; had the foundation been included in this estimate diversion would have been over 80%.

Diverted materials included aluminum and steel flashing and fixtures, iron pipes and window components, asphalt shingles, and clean wood for recycling as well as framing lumber, flooring, bricks, doors, windows, cabinets, and fixtures for reuse. As the house had been abandoned for some time and was in a state of disrepair, appliances and bathroom fixtures were not present for salvage and reuse but would have positively contributed to the diversion rate and would presumably do so in most other deconstruction projects. Similarly, the siding material could not be salvaged due to many layers of asbestos shingle over the wood clapboard siding, however in most other deconstruction projects the siding is salvaged for reuse following removal of lead based paints. Siding would also have positively contributed to the diversion rate.

Waste materials sent to landfill in addition to the siding mentioned above included carpeting, shake roofing, skip sheathing, laminate flooring, drywall, plaster, damaged windows and doors, pressure treated lumber, and insulation.

Jobs

Deconstruction resulted in the creation of 5 to 7 jobs where one job would have been required for demolition. Demolition typically involves one or two skilled heavy machinery operators per job site. The pay for such operators is at the high end of the construction pay scale. Deconstruction pay ranges from $10-$15 for an inexperienced worker to $30-$40 for a supervisor, who may oversee three to five projects at any given time. A crew chief earning $18-$30 is generally on site as well.

The New Haven pilot deconstruction training program was completed in eight days using the equivalent of a six person crew, for a total of 384 worker hours or 48 worker days as compared to the 64 worker hours or 8 worker days that would be required to demolish the house.

Materials and Methods

A dynamic systems model was created to address the questions above using Stella v.9.1.4 modeling software made by iSee Systems (iSee, 2010). The model describes the construction and demolition material flows in the City of New Haven, Connecticut beginning in the reference year, 2010. In particular, the model focuses on the implications of different building materials management policy options for landfill disposal, reuse, and recycling of building materials and on the potential for offsetting new materials by reused materials in new building construction.

This study and the accompanying model are intended as a policy tool for City of New Haven officials considering a suite of regulatory options for reducing the building material sent to landfills each year from the City and reducing the greenhouse gas emissions (GHGs) associated with the fate of disposed building materials and the embodied energy and emissions associated with the production of new building materials. The model also explores the economic impact of different proposed ordinances and internal municipal policy language in terms of materials management costs to the City and to private property owners as well as the potential for job creation.

Three main sections of the model track building material quantities, economics, and environmental impact. The materials section is the foundation of the model and measures building materials entering and leaving the New Haven building material stock. The economics section tracks the costs of two different modes of building removal when coupled with three different material fates as well as the full-time jobs required to complete the removal of those buildings removed annually by deconstruction. The environmental section gives an estimate of the metric tons carbon equivalent (MTCE) emitted in the management of construction and demolition debris (C&D) leaving the New Haven building stock.

Material Section

The two main drivers of the building materials section of the model are the construction and demolition sector, documented in square feet of commercial, industrial, residential, or residential utility (garage and storage) added to and removed from the New Haven building stock annually and the corresponding flows of material disaggregated by material type.

The United States Census Bureau collects annual housing data including the number of single family housing units completed, the number of two-family and multi-family housing units completed, and the average floor area of the different housing unit types. These data were available for New Haven, Connecticut for the years 1996 through 2009 (US Census Bureau, 2010). The City of New Haven Building Department keeps historical records of all building and demolition permits filed in the city, however, only the most recent 12 months are summarized by permit type, cost, location, and property owner; all other records are filed by address in physical files only which made cross-checking Census Bureau data by year or looking up commercial, industrial, or residential utility data by year for years prior to the reference year impractical for this study.

Data for the reference year, here referred to as 2010, were collected for new construction permits from November, 2009 through October, 2010 and for demolition (building removal) permits for FY2010 or August, 2009 through July, 2010. While these dates are not perfectly concurrent, they are treated as such for this analysis as they both cover twelve-month periods that are temporally very close to each other.

Available building removal data included address, owner, building type, cubic feet, floor area, and in many, but not all, cases the presence or absence of asbestos containing material. New construction data included address, owner, building type, total number of permits, and in the case of residential buildings, number of units. The total number of permits was used to calculate the number of rehabilitation permits issued by subtracting new residential, commercial, industrial, and residential utility permits.

New construction floor area was derived for single family and two- and multi-family buildings by applying the average annual growth rate for the floor area of single family houses in New Haven of 1.0% per year and the average annual growth rate for the floor area of two-and multi-family units of 1.4% per year (US Census Bureau, 2010) to the most recent year for which Census data was available, 2009, and multiplying by number of units as described by the building permits to find total square feet of new residential construction for 2010. This method was necessary as building data is not yet available from the United States Census Bureau for 2010.

Lower and upper bound estimates were derived for the ratio of square feet per average industrial, commercial, and residential utility building to residential buildings and these bounds were used along with the number of such permits filed for 2010 to estimate the lower and upper bounds of total square feet of new construction for these building categories. Lower and upper bound estimates for the ratio of total square feet of rehabilitation, also known as renovation, to new construction were estimated based on estimates of square footage for the average renovation, the average square footage of existing structures from the 2010 demolition data, and the number of rehabilitation permits issued in respect to new construction permits. More discussion of this approach, sources for data, assumptions, and verifications from other data sources are included in Appendix C and Appendix D. One interesting finding from this is that rehabilitation permits on average outnumber new construction permits by approximately 50 to 1 annually in New Haven, but that the relative size of rehabilitation to new construction means that annual rehabilitation square footage is roughly equal to new construction square footage. Square feet of rehabilitation added annually are assumed to equal square feet of rehabilitation removed annually.

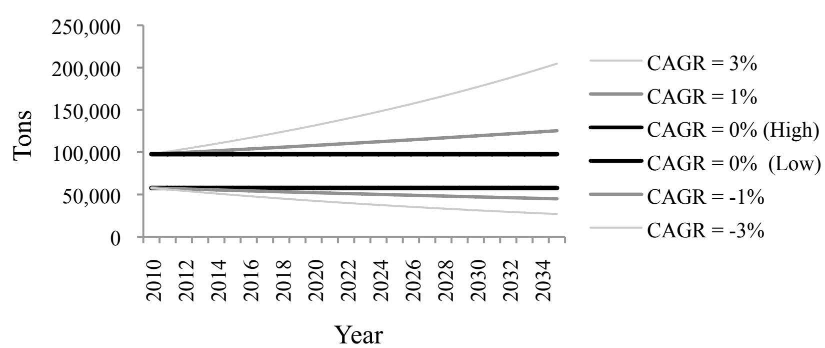
Sensitivity variables for the growth of new construction and removal annually and their ratio to one another were used to project new construction and removal square footage rates for 25 years. Uncertainty about the rate at which new construction will grow or decline in New Haven stems from a general lack of prediction about the construction sector over that length of time and from the focus of current data collection by the U.S. Census Bureau on residential buildings. The model therefore does not predict this growth or decline but provides a wide range of possible values within which the actual rate of square feet of new construction is expected to fall. The bulk of the uncertainty presented in the results for total material managed in the scenarios described below comes from this uncertainty about new construction rates into the future.

The compound annual growth rate (CAGR) for square feet of new residential construction in New Haven, Connecticut, for the years reported by the Census Bureau, 1996 to 2009, was -0.08%, but the annual variation was anywhere between -87.00% and +269.00%. This was a particularly tumultuous time for the construction industry and it is extremely difficult to say what growth rate will be over the next 25 years. A range of -3% to 3% compound annual growth was selected as a broad range of uncertainty, capturing what is a highly likely growth rate of around 0%. The variation in possible futures for the growth or decay of C&D managed is shown in Figure 1 for ranges of -3% to 3%, -1% to 1%, and for the uncertainty in tonnage around 0% growth. Further discussion of growth rate sensitivity and other sensitivity variables is included below and in Appendix D.

From the square footage totals described above, building material tonnage totals were calculated by the model annually using ton per square foot figures for each of the four building types. These calculations were made for 16 building material types: composition shingle roofing, shake shingle roofing, membrane roofing, clapboard siding, vinyl siding, masonry siding, interior drywall covering, interior plaster covering, wood flooring, sheathing, wood framing, steel framing, structural masonry, foundation, fixtures, and miscellaneous debris.

Tons per square feet vary by building type and were calculated using the average square footage of buildings removed by type in 2010, calculations for volume per building by building

Figure 1. Uncertainty in C&D Managed over 25 Years with Alternative Futures for New Construction Growth Rate



The lower and upper bounds for 0% growth describe the uncertainty in the model not related to uncertainty in new construction rates – compound annual growth rate, CAGR. All other uncertainty arises from uncertainty in new construction rates.

type for each material (Reiff, 2010a) and weight per volume for each material (Falk and Guy, 2007). Total tons per square foot by building type were verified against statistics for another municipality (Contra Costa, 2010) and by statistics generated during the deconstruction of the case study wood frame house, 183 Saltonstall Avenue, described above, as well as a home deconstructed in Greenwich, Connecticut in 2010 (Yurish, 2010). Rehabilitation materials totals in the model exclude foundation material, as this is assumed to remain unchanged in the majority of rehabilitation cases.

Previous studies of deconstruction materials management and generation have focused on residential, wood frame construction and a great deal of data is available for this construction type. This study expands the range of building types considered greatly and into other modes of construction, namely structural masonry and steel framing. As such, the model has a residential building bias, but nonetheless gives accurate estimates of commercial and industrial building material generated through the removal of these building types. Further discussion of these methods, data sources, and assumptions are found in Appendix C.

The model calculated the tonnages of material generated during removal and allowed for reuse of these materials in new construction. The extent of this reuse depended on whether or not a warehouse was available in New Haven for sorting and reselling reused materials, on whether or not deconstruction and building material reuse were required in New Haven and to what extent, and on the rates of market growth assumed for reused building materials in each scenario, as discussed in the results section below.

Economic Section

The two functions of the economic section of the model are to calculate the costs of removing buildings by demolition versus deconstruction and to count the full-time construction sector jobs potentially created by deconstructing buildings. As demolition was assumed to be the current building removal method of choice in New Haven, much demolition work is accomplished by heavy machinery, and demolition employs relatively few heavy machine operators per job, demolition jobs lost as a result of deconstruction was assumed to be minimal. Jobs data for demolition were therefore not included and only new deconstruction jobs were counted.

Full-time jobs created by deconstructing buildings was calculated by the model for each scenario using deconstruction project duration per square foot data and laborers per deconstruction project data from two sources. The first came from the case study project and the second was Dentata, et al. (2005) which provided a survey of deconstruction projects. The two sources returned similar values for both variables and by multiplying hours per square foot by the number of laborers per project an average laborer hours per square foot rate of 0.37 and was used in the model. The model multiplied this rate by the number of square feet deconstructed for each building type annually to arrive at a total for laborer hours per year. Using the average annual hours worked per full time construction laborer job from the U.S. Bureau of Labor statistics (2010), the full-time job equivalents created per scenario was calculated. This figure is a slight overestimate, as the number of demolition jobs displaced by deconstruction jobs is unknown. However, as with the case study house, for every 1 demolition job lost, approximately 5 to 7 deconstruction jobs were created.

Deconstruction cost per square foot was calculated using hauling fees, tipping fees, and truck rental costs per ton for each of the various materials and destinations for the cast study house and the average tons per building type calculated for the materials section of the model. This figure was divided by average square feet per building type to give a disposal cost per square foot. To this was added the average cost per square foot for mechanized hardscape removal, calculated from the residential case study example and adjusted proportionally by average square feet for each building type. Labor costs per square feet were derived from the labor hours for square foot and a minimum and maximum pay rate for construction laborers in Connecticut was used in sensitivity analysis as described below. These costs per square foot were totaled and the Connecticut going rate for profit, supplies and overhead of 40% (Reiff, 2010a) for construction projects was added to this rate. This rate is that used by The Reuse People – a national deconstruction firm – when calculating their bids for deconstruction projects in the state of Connecticut and is at or above the rate used by the contractors who participated in the pilot New Haven Deconstruction Training Program.

Demolition costs per square foot were available from an internal study conducted by the City of New Haven Office of Economic Development Small Business Construction Program in the Summer of 2010 that surveyed average demolition costs per square foot for a range of projects in the City (Snyder, 2010b). A detailed breakdown of demolition costs as given for deconstruction costs above was not available as demolition companies regard this as propriety information. The minimum and maximum demolition costs per square foot were used in sensitivity analysis of the model as described below.

Abatement costs per square foot were assumed to be identical for deconstruction and demolition. All buildings containing lead and asbestos are required by law to have these toxins abated before removal, and because of the age of buildings in New Haven, all removed buildings were assumed to have both lead and asbestos and therefore were assumed to require abatement. Abatement was assumed to successfully free up materials for reuse, although in reality a portion of materials requiring abatement may not be reusable. As building stock becomes newer and as more time passes between the banning of lead and asbestos in new construction and the date a building is removed fewer and fewer buildings will require abatement before removal. The abatement figures used in this model are therefore an increasing overestimate for later years, but as they are identical for the two removal modes studied this is not a problem for comparing these two modes. Abatement costs per square foot were derived from the same City of New Haven Economic Development Small Business Construction Program survey described above, were separate from demolition costs, and were therefore added on a per square foot basis to both deconstruction and demolition costs in the model.

Further explanation of cost calculations, sources, and assumptions can be found in Appendix B.

Environmental section

The environmental impact section of the model measures the GHG emissions associated with the disposal of each material for of each of three material fates as per the scenarios below. This provides a total figure for GHG emitted in the management of removed building material for the City of New Haven annually. For each of the 16 materials listed above, metric tons carbon equivalent (MTCE) emitted for landfilling, recycling, and reuse were calculated resulting in a MTCE per ton figure using the EPA WARM model (EPA, 2009; Appendix B). Note that this is not the same as an estimate of carbon dioxide emissions. The WARM model reports emissions in elemental carbon, not carbon dioxide. Because the molecular mass of carbon dioxide is roughly 3.6 times that of elemental carbon, the estimate for carbon dioxide emissions would be approximately 3.6 times higher than those shown here for carbon alone. This figure is then used in conjunction with material generation tonnages from building removal for the fates prescribed by each scenario's material management regimen. The WARM model provides several general categories of municipal solid waste into which all of the 16 materials described here were placed. The WARM model also accounts for avoided emissions in the reuse or recycling of materials for new applications thus providing the partial lifetime benefits of reuse or recycling of building materials here and often resulting in negative emissions values for certain materials. Distance to landfill is one of the WARM model inputs, and all C&D from Connecticut was assumed to be delivered to Cleveland, Ohio as per current Connecticut Department of Environmental Protection understanding (Baldwin, 2010), 537 miles from New Haven.

The WARM model as used here also assumes that landfill gas recovered is used for energy and that source reduced material offsets material using the current national mix of virgin and recycled material. MTCE is used here as a proxy for all environmental impacts, though the range of impacts reaches far beyond GHG emissions to acidification and eutrophication potential as well as natural resource depletion and toxic waste hazards. These impacts should be considered in further studies employing a full lifecycle analysis approach. For more discussion of the implementation of the EPA WARM model to quantify environmental impacts as used in this study, and a discussion of the categorization, sources, and assumptions behind the material and fate analysis used here, see Appendix B.

Equations

All model equations may be found in Appendix E. Where equations vary between model iterations as dictated by the scenarios below, these deviations are mentioned at the end of the appendix.

Sensitivity Analysis

Several variables in the model are either uncertain or highly unpredictable in reality and are therefore the basis for sensitivity analysis. Variables with a low uncertainty were fixed in the model at average observed levels (e.g. the cost of container hauling and waste disposal in New Haven) while others with low uncertainty but a known range were allowed to vary between sensitivity runs. The sensitivity variables were divided into two categories: those concerning the area of buildings and the mass of materials, and those concerning the cost of materials management techniques. Area and mass sensitivity variables include the annual growth rate for new construction area, the ratio of rehabilitation area to new construction area, the ratio of commercial, industrial, and residential utility building area to residential building area, the ratio of building removal to new construction, and the tons per square foot for fixtures. Cost sensitivity variables include the price per square foot for asbestos and lead abatement, the price per square foot for demolition, and the wage rate for demolition laborers. The possible values for these variables were then grouped into low and high clusters and two combinations of these variables were used in the final model: the lowest area and mass values coupled with the lowest cost values, and the highest area and mass values coupled with the highest cost values. These two combinations provide the extreme bounds for model results. A full discussion of the sensitivity analysis incorporated into the model can be found in Appendix D.

Scenarios

Five policy and market scenarios are presented in the results section below. 41 different results values describing possible building construction and removal, building material quantity, environmental, and economic outcomes were measured for each scenario. Salient results are presented below.

Results

Environmental, planning, and economic development officials in the municipal government of New Haven are faced with a suite of options for growing the building materials reuse sector and reducing the environmental impact of building removal within the city limits. This section discusses the policy options currently being discussed by officials, given the stated imperative to increase efficiency and reduce waste through an expanding deconstruction market. Each scenario and the various outcomes generated by the dynamic systems model described above are discussed.

Of particular concern to municipal officials is the economic impact of regulations or market-based means of expanding deconstruction in New Haven. The uncertainty inherent in several of the model's variables will affect how the results presented below should be interpreted. The ranges for construction rates and costs are presented here with all other variables discussed in Appendix D.

Two approaches were taken to calculating the new construction rate for residential buildings from which the new construction rates for the three other building types were calculated. While Census data from 1996 to 2009 shows growth in the average square feet of new residential units, the annual variation in the growth rate for total new residential construction is highly variable ranging from -87.00% to 269.00% (US Census Bureau, 2009). For the purposes of this model, and taking a long term view, the alternatives of a 3% annual growth rate and a 3% annual decline in new construction of residential buildings was assumed. These growth and decline rates incorporate expectations about the number of new residential buildings constructed and their size and reveal a reasonable window of expectations for square feet of new residential construction in New Haven over the next 25 years given New Haven's fairly stagnant population (CERC, 2010). The results reveal a range for new residential construction either growing from the 2010 rate of 96,500 square feet per year to over 200,000 square feet per year or shrinking to just over 45,000 square feet per year.

Ranges for the ratio of square feet of construction for the three other building types to residential construction in combination with the growth rate range for new residential construction produced a low estimate of over 1.3 million square feet per year of total new construction and renovation in 2010 shrinking to over 630,000 square feet per year of total new construction and renovation in 2035 and a high estimate of total new construction and renovation of over 3.3 million square feet per year in 2010 growing to over 6.9 million total square feet per year in 2035.

Ranges for the rate of removal of existing buildings and renovation square footage to the rate of new construction and renovation produce low and high estimates for square feet of building removal per year. The low estimate begins at over 1.6 million square feet per year in 2010 and shrinks to just under 750,000 square feet per year in 2035 and the high estimate begins at over 3.1 million square feet per year in 2010 and grows to almost 6.6 million square feet per year in 2035.

The uncertainty in abatement and demolition costs and deconstruction labor costs lead to important conclusions about the cost of different C&D materials management options. While the common assumption is that deconstruction is always more expensive than demolition before potential tax credits are counted (Reiff, 2010b; Carter, 2010; Dentata, et al., 2005), this is not always the case.

In the City of New Haven Office of Economic Development Small Business Construction survey abatement costs were found to vary for residential buildings between $2.49 per square foot and $10.67 per square foot. Calculating these costs for other building types (Appendix D) produced a range of $1.56 per square foot to $6.69 per square foot for residential utility buildings, $2.75 per square foot to $11.79 per square foot for commercial buildings, and $2.06 per square foot to $8.81 per square foot for industrial buildings. Demolition costs for residential buildings varied between $10.69 per square foot and $36.06 per square foot, and were calculated to vary between $6.70 per square foot and $22.61 per square foot for residential utility buildings, $11.82 per square foot and $39.86 per square foot for commercial buildings, and $8.82 per square foot and $29.91 per square foot for commercial buildings. All cost amounts throughout this report are given in constant 2010 dollars and are before tax incentives for deconstruction are accounted for.

While the lower bound for deconstruction costs was higher than for demolition costs, the range was smaller. For most building types this resulted in lower overall costs for deconstruction than demolition when higher demolition costs prevailed and higher overall costs for deconstruction when lower demolition costs prevailed. This is the situation observed for the case study house, revealing that even before tax incentives, deconstruction may be less expensive than demolition in New Haven, Connecticut, although this is highly dependent on demolition costs. Deconstruction costs are mainly driven by labor and disposal fees, where as demolition costs are driven by equipment (capital) costs and disposal fees. In a state such as Connecticut, where disposal fees are extremely high, the difference in disposal cost between deconstruction and demolition can tilt the financial benefit to deconstruction. Deconstruction costs were found to vary between \$15.60 per square foot and \$28.16 per square foot for residential buildings, between \$12.59 per square foot and \$25.02 per square foot for residential utility buildings, between \$17.14 per square foot and \$29.70 per square foot for commercial buildings, and between \$14.35 per square foot and \$26.91 per square foot for industrial buildings. These results, abatement, and demolition costs are summarized in Table d in Appendix D.

Scenario 1

Scenario 1 represented the business-as-usual (BAU) course of action for regulation of building removal methods in New Haven, and assumed no growth in the use of deconstruction, reuse, and recycling as alternatives to demolition and landfilling. This scenario also assumed that neither public nor private interests would build a warehouse or reuse store in New Haven to facilitate building material reuse.

As a BAU scenario, this outlook most likely represents an overestimate of the tons of C&D originating in New Haven that are eventually landfilled as the only recycled material is assumed to be steel. In fact, as of this writing, New Haven currently has two recycling and transfer operations operating within its city limits that are capable of processing C&D other than steel, and most likely deal largely with concrete, masonry, and asphalt which can be processed into clean fill or aggregate (Dion, 2001). However, in the absence of verifiable information about their recycling rates versus transfer to landfill rates, it is impossible to make assumptions about diversion from landfill occurring through these facilities. There are also several recycling facilities near New Haven that most likely process some of the C&D originating in the City. While these additional recycling facilities may exist, the proportion of C&D handled by these recyclers that is eventually recycled may vary with space capacity constraints and some or all of the material processed by these facilities may be destined for landfills (Dion, 2001).

The C&D generated in each scenario was identical, but different materials management options dictate different fates for that material. For the lower model bound materials amounted to nearly 58,000 tons per year in 2010 and shrank to just under 27,000 tons per year in 2035. For the higher model bound the material generated per year was just under 98,000 in 2010 and climbed to over 204,000 tons in 2035 (Table 1). Scenario 1 had the lowest diversion rate with a lower bound of 2,082 tons per year and an upper bound of 4,459 tons per year in 2010. This diversion was only in the form of recycling and represents a lower bound of 3.61% and an upper bound of 4.56% of C&D diverted annually.

As is to be expected with the lowest diversion rate from landfill, scenario 1 resulted in the highest annual MTCE emissions for both the upper and lower bounds of the model. The costs of this building removal scenario however were the lowest of all the scenarios at the lower bound, but were only the 4th lowest (out of 8 scenarios and sub-scenarios) at the upper bound of the model because of the wide variability in demolition costs in New Haven (Table 10).

As the model only counted new deconstruction jobs created, this scenario did not result in any jobs created.

Scenario 2

In this and all subsequent scenarios, a reused building materials warehouse or resale store was assumed to be open at the beginning of 2013. In fact, planning for such a warehouse is currently underway by City of New Haven officials and a private waste management firm. In the model, the presence of this warehouse allowed for the reuse of building materials in the construction of new buildings and renovation projects within the City, whereas in its absence all reused building materials were assumed to be reused outside of New Haven (as Connecticut reuse facilities are currently located outside of New Haven city limits and cater to a broad area). If materials available for reuse in New Haven exceeded the demand for new materials as predicted by the construction rate for various buildings types, excess material was assumed to be reused outside of New Haven.

Scenario 2 predicted the material generated for reuse and recycling through deconstruction activities as opposed to landfilling following demolition given growth in the demand for deconstruction as a result of a building material reuse warehouse opening in New Haven. Beginning in 2013, this scenario tested a growth in demand for deconstruction of 5% per year for commercial and industrial buildings following an initial 1% capture in the market for removal of these building types and growth in demand for deconstruction of 10% per year following an initial market capture of 5% for residential and residential utility building removal. This growth occured in tandem with the lower and upper bounds for new building and renovation as described above.

Scenario 2 began with the same diversion rate as scenario 1 in 2010, but gradually grew from 3.61% to 8.38% of material generated at the lower bound from 2010 to 2035, and grew from 4.56% to 8.61% at the upper bound as more building removals and renovations employed deconstruction techniques. The majority of this diversion was from recycling, not reuse, do to the likely fate of concrete, masonry, and steel building components from commercial and industrial buildings (Figure 3). While these two building types do not make up the largest proportion of new construction or demolition permits filed annually in New Haven, they do make up the largest portion of square footage built and removed annually.

Scenario 2 resulted in the 2nd highest level of MTCE emissions at the lower and upper bounds, had the 3rd lowest cost at both bounds, and resulted in the 3rd lowest number of deconstruction jobs created (Table 9 and Table 10). From the initiation of this scenario in 2013, the cost of avoided emissions began at $4,740/ton avoided MTCE in 2010 and shrank to $2,810/ton avoided MTCE in 2035 at the lower bound and began at $2,731/ton avoided MTCE in 2010 and shrank to - $6/ton avoided MTCE at the upper bound in 2035. This declining cost at both the upper and lower model bounds, and the transition to a cost savings at the upper bound, is a result of the lower maximum cost of deconstruction compared with the maximum cost for demolition as a higher percentage of buildings employ deconstruction techniques. Costs per deconstruction job created showed a similar trend as overall costs for all building removal and renovation in the City of New Haven declined over that same time period in this scenario.

Cost per ton of material diverted from landfill in this scenario grew at the lower bound due to the lowest potential demolition costs and higher deconstruction costs, but shrank over the time period studied at the upper bound of the model for the same reasons as discussed above. This scenario had one of the higher rates of MTCE emissions avoided per ton material diverted, despite the low total material diversion and avoided emissions (Table 2).

Scenario 3

While scenario 3 assumed that a reuse warehouse would open in New Haven in 2013, no spontaneous growth in the demand for deconstruction as a result was assumed in this or any subsequent scenarios. Instead, the presence of a warehouse simply dictated whether or not reused building materials were reused in New Haven or outside the City.

This scenario tested the economic and environmental impact of using deconstruction rather than demolition for municipal buildings slated for removal. This policy is one currently being considered by New Haven officials as an alternative to mandating deconstruction or other materials management ordinances regarding the removal or renovation of privately owned buildings and one which can be accomplished without legislative action.

For the purposes of this scenario and based on current actions by the City to prioritize deconstruction of city-owned residential buildings, a phased approach to requiring deconstruction for city projects was assumed. Beginning with deconstruction of all city-owned residential and residential utility buildings removed by the city in 2011, commercial buildings owned by the city were deconstructed as opposed to demolished beginning in 2012, and industrial buildings were deconstructed beginning in 2013.

In 2010, 6 out of 21 of the residential and residential utility buildings removed in New Haven were owned by the city, 1 out of 14 of the removed commercial buildings were city-owned, and 0 out of 3 of the industrial buildings were owned by the city. These ratios were assumed to hold for all years following 2010 as the City of New Haven is one of the largest property owners in the City and frequently removes or renovates buildings.

Scenario 3 had a slightly higher diversion rate than scenario 2 as a result of projecting deconstruction for all municipal buildings rather than simply assuming growth in the market for deconstruction without mandating deconstruction (but 4th lowest overall, Table 3) at both the upper and lower bounds of the model growing to 8.87% and 8.92% respectively by 2014 from which point they remained flat. This was again largely due to recycling. Emissions were the 3rd highest while costs were the 4th lowest at the lower bound and the 4th highest at the upper bound. Deconstruction jobs created were the second lowest in both cases.

Cost per avoided MTCE emissions fluctuated slightly until 2014 at which point they stabilized between $3,577MTCE and $4,396/MTCE (at the lower and higher bounds). Cost per job created were stable and much higher than in scenario 2. Cost per ton diverted above scenario 1 diversion were also more than double those for scenario 2 at both the lower and upper model bounds.

Scenario 4

Scenario 4 was made up of four sub-scenarios, each representing the effect of a city-wide requirement to use deconstruction removal methods instead of demolition for all buildings of a certain type. Scenario 4a tested the model's response to a deconstruction requirement for all residential and residential utility building removal and renovation beginning in 2011.

Scenario 4a resulted in a flat 8.3% diversion rate at the model's lower bound and a flat 8.15% diversion rate at the model's upper bound from the first year it was introduced through 2035. The lower bound diversion rate is higher than the upper bound diversion rate (though the lower bound real value is much lower than that at the upper bound) due to a benign anomaly in the model that appears in this and some of the following scenarios. This is due to the ratio between new construction and building removal, in this case the ratio for residential utility buildings. Because removal is known for 2010, but new construction is estimated, the numerator in the ratio does not change but the denominator does. The removal ratio is higher when the estimate for the new construction rate is lower – at the lower bound. Likewise, when the estimate for the new construction rate is higher, the removal ratio is lower. This is further explained in Appendix D.

The total material diverted in this scenario increased or decreased with total construction activity and reuse was outweighed by recycling in this scenario though not by as large an amount as in some other scenarios. This consistency was due to the fact that the ratios of different building types do not change with time in the model. However, these results reveal that simply deconstructing residential and residential buildings and employing deconstruction techniques for residential and residential utility renovations results in little improvement in the amount of C&D landfilled from New Haven. Part of this affect arose from materials that cannot be recycled or reused in New Haven at this time, such as drywall and miscellaneous debris, though improved recycling facilities and source separation techniques may change this in the future.

This scenario had the 3rd lowest diversion rate but only the 5th highest emissions rate due to the reusability of many fixtures and materials from residential buildings. Costs were the second lowest, and deconstruction jobs created were the 5th highest for this scenario.

Scenario 4a had one of the lowest costs per MTCE emission avoided at a constant $1,067/MTCE at the lower bound and -$2,543/MTCE at the upper bound. Cost per job created showed a similar pattern oscillating around $15,460/job created for the lower bound and

-$41,840/job at the upper bound. Cost per ton diverted showed a similar efficiency at higher removal and renovation rates and this scenario exhibits one of the most efficient ratios of avoided MTCE emissions per ton of diverted C&D material (Table 10).

While cost estimates for deconstruction versus demolition were confined to those before tax benefits due to data limitations and the overwhelming amount of material originating from commercial and industrial buildings that was recycled but not reused in this model, it is possible when considering just residential buildings to apply average tax benefits (in the form of tax deductions) from reusable material donations to the cost comparison above.

Reiff has reported on the donation values and tax savings of several homes deconstructed by The Reuse People across the country, assuming an income tax rate of 35% (Reiff, 2010c). These tax savings were converted here to savings per square foot and range from $8.75 per square foot to $22.01 per square foot with an average of $14.41 per square foot for 26 houses in California, Colorado, Kansas, Illinois, Washington, and Wisconsin. Dantata et al. estimated the potential tax benefits from deconstruction in Massachusetts to be between $1.50 and $2.45 per square foot (2005).

Taking the low Dantata et al. estimate and the average from The Reuse People data we can calculate total potential deconstruction benefits to residential property owners in New Haven, and describe the cost of deconstruction after tax benefits. Because the tax benefits of donating building materials removed by deconstruction accrue directly to the project's owner, they can be calculated as a direct savings of removing a building by deconstruction as opposed to demolition. Total tax benefits at the lower bound of the model range between $230,401.92 and $2,213,394.45 for all buildings in New Haven and at the upper bound of the model range between $320,734.89 and $3,081,193.18 in 2011, the first year residential deconstruction would be required. Just in 2011 these tax benefits reduced the total cost of scenario 4a to between $18,570,075.07 and $20,553,067.60 at the lower bound and between $141,309,824.20 and $144,070,282.50, making this the lowest cost scenario.

Scenario 4b tested the response to a commercial building removal and renovation deconstruction requirement beginning in 2011. Here the percent diversion was testament to the mass of building material in this building type in the City of New Haven as the diversion rate was a constant 51.42% and 46.12% at the lower and upper bounds respectively. As was to be expected, this scenario had the 2nd lowest MTCE emissions rate. Costs were the 2nd highest for the lower bound of the model and highest for the upper bound of the model. Jobs created were also 2nd highest in all cases.

Costs per ton diverted, per MTCE emissions avoided, and per job created were all high as was to be expected by the costs described above. The efficiency of MTCE emissions avoided per ton of C&D material diverted was low for this and the next two sub-scenarios described (Table 9 and Table 10).

Scenario 4c predicted the economic and environmental costs and benefits of an industrial building removal and renovation deconstruction requirement beginning in 2011. Diversion rates for this scenario were roughly half those of scenario 4b, which describes the relative number of industrial buildings removed and renovated compared with commercial buildings in New Haven. These rates were 21.6% and 25.34% at the model's lower and upper bounds respectively.

Interestingly, this scenario had the 4th highest MTCE emissions rate, and the 4th highest cost at the model's lower bound, but represented a huge cost savings opportunity if construction activity in general grows in New Haven as predicted by the model's upper bound. At this level of activity each avoided MTCE of emissions resulted in an $8,904 savings over the BAU scenario.

Scenario 4d was the most extreme scenario tested in this report and tested the model's response to a ban on all demolition in New Haven and a requirement that all building removal and renovation must employ deconstruction techniques beginning in 2011 as some city representatives have suggested (Snyder, 2010a).

As expected, this scenario represented the highest diversion rate achieved by any of the scenarios at 74.1% and 70.48% at the model's upper and lower bounds respectively for the years this policy was in place. Less than 1/10th of that diversion was from reuse, the bulk of the tonnage diverted from landfill was recycled as it was concrete, masonry, and steel, largely from non-residential buildings.

Scenario 4d is the most expensive at the model's lower bound and the 2nd most expensive at the upper bound. This scenario resulted in the largest reduction of MTCE emissions and the largest creation of jobs. However, costs per avoided MTCE emissions, costs per job created, and costs per ton of C&D diverted were all high compared with the savings projected for some of the other scenarios.

Scenario 5

Scenario 5 tested the model outcome using proposed building materials management guidelines for new construction and renovation in New Haven from a draft Green Building Policy for the City. The policy concerns building operations and design as well as materials management, but this study confined requirements to those pertaining to materials generated through removal and renovation.

The draft of the policy stipulates that for all renovations over 2,000 square feet, all new construction valued over $50,000, and all demolition over 2,000 square feet a materials management plan detailing how waste materials suitable for reuse are to be reused. If the project generates reusable materials but they will not be reused, donated for reuse, or sold for reuse, an exception must be applied for. The policy recommends recycling but does not require it. For the purposes of this scenario, any building that is deconstructed is assumed to take advantage of the full range of recycling options available for non-reusable materials as recycling is potentially much less expensive than landfilling in New Haven once recyclable materials have already been source separated as a result of source separating reusable materials.

The $50,000 construction value requirement in the policy is ignored here as this model only deals with material generated in removal and renovation, not waste material generated during new construction, which is a very small amount compared with removed building material in any case (Contra Costa, 2010). That leaves the two removal and renovation requirements for buildings or projects over 2,000 square feet.

The average residential renovation in 2010 was well under 2,000 square feet based on the number of residential renovation permits granted and the estimated square footage and tonnage of materials generated for renovations in that year, so residential renovations are excluded from deconstruction in this scenario. The same proportion of industrial and commercial removals over 2,000 square feet is assumed to hold for renovations of these building types. The scenario also assumes that 50% of buildings removed or renovation projects will be granted exceptions to the policy. As this policy is still in draft stages and rules for granting exceptions, penalties for not complying with the policy, and means of enforcing the policy have not yet been considered, it is difficult to do more than speculate over what the actual compliance rate will be.

In 2010, 10 out of 14 commercial buildings removed were over 2,000 square feet. Assuming a 50% compliance rate with the policy, this led to a 36% deconstruction rate for commercial buildings in the model. 2 out of 3 industrial buildings were over 2,000 square feet leading to a deconstruction rate of 33%. 3 out of 9 residential buildings were over 2,000 square feet for a 17% deconstruction rate (excluding renovations) and 0 residential utility buildings were over 2,000 square feet. All of these rates, with the exception of the 0% rate for residential utility deconstruction, were allowed to grow at 1% per year, to account for increasing average sizes in the building stock pushing buildings above the 2,000 square foot cutoff for this policy. This 1%

growth rate in average size is the same growth rate observed for residential buildings in new haven from 1996 to 2009.

Scenario 5 resulted in the 3rd highest diversion rate over the lifetime of the policy growing from 27.32% in 2010 to 33.71% in 2035 at the lower bound and growing from 26.8% to 32.8% at the upper bound (Table 5). Again, recycling tonnage dwarfed reused material tonnage due to the amount of concrete and masonry material removed from industrial and commercial buildings in compliance with the proposed New Haven Green Buildings policy.

Emissions were the 3rd lowest of all of the scenarios while overall costs before tax incentives were the 3rd highest. Jobs created were the 3rd highest at the lower bound and the 4th highest at the upper bound. As opposed to some examples from scenario 4, in no cases did cost per ton diverted material, cost per avoided MTCE emissions, or cost per deconstruction job created represent a savings over the BAU, scenario 1.

Table 1. Scenario 1 results (no deconstruction).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2010	Low	3.61	4,112	20,849,336	0
	High	4.56	7,533	142,322,768	0
2035	Low	3.61	1,920	9,736,112	0
	High	4.56	15,773	297,992,271	0

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 2.

Table 2. Scenario 2 results (assume 5% annual growth in commercial and industrial deconstruction following 1% market capture and 10% growth in residential deconstruction following 5% market capture).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2013	Low	4.68	3,700	19,279,134	5
	High	5.52	8,130	155,795,855	11
2035	Low	8.38	1,753	10,275,155	14
	High	8.61	14,596	297,985,739	101

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 3.

Table 3. Scenario 3 results (all municipal buildings deconstructed).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2011	Low	5.52	3,766	20,445,028	15
	High	6.01	7,395	145,636,542	21
2035	Low	8.87	1,763	10,424,564	13
	High	8.92	14,674	301,921,635	88

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 4.

Table 4. Scenario 4a results (all residential and residential utility buildings deconstructed).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2011	Low	8.30	3,459	20,783,469	36
	High	8.15	6,887	144,391,017	52
2035	Low	8.30	1,667	10,005,520	17
	High	8.15	14,014	293,517,209	107

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 5.

Table 5. Scenario 4b results (all commercial buildings deconstructed).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2011	Low	51.42	2,486	37,493,570	169
	High	46.12	5,199	187,862,394	321
2035	Low	51.42	1,197	18,050,050	81
	High	46.12	10,569	381,885,566	652

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 6.

Table 6. Scenario 4c results (all industrial buildings deconstructed).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2011	Low	21.60	3,657	22,736,106	121
	High	25.34	7,069	140,445,261	305
2035	Low	21.60	1,760	10,945,553	58
	High	25.34	14,370	285,496,298	620

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 7.

Table 7. Scenario 4d results (all buildings deconstructed).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2011	Low	74.10	1,624	40,565,434	326
	High	70.48	3,637	179,513,769	678
2035	Low	74.10	784	19,528,899	157
	High	70.48	7,406	364,914,532	1379

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 8.

Table 8. Scenario 5 results (New Haven Green Building Ordinance draft policy).

Year	Low/High	% Diversion*	Total MTCE	Total Cost	Total Deconstruction Jobs
2010	Low	27.14	3,374	27,955,596	106
	High	26.63	6,413	155,822,984	215
2035	Low	33.71	1,495	14,108,870	64
	High	32.80	12,646	331,079,177	571

*For comparisons of reuse versus recycling diversion from landfill, and for landfill total, see Figure 9.

Table 9. Lower bound normalized cost and avoided emissions estimates for each scenario.

Scenario	First Year Enacted* Final Year	$/avoided MTCE	$/deconstruction job	$/ton diverted	Avoided MTCE/ ton diverted
Scenario 1	2010	0	n/a	0	0
	2035	0	n/a	0	0
Scenario 2	2013	4,740	46,219	102	0.093
	2035	2,810	33,082	207	0.130
Scenario 3	2011	996	14,914	72	0.207
	2035	4,396	53,660	288	0.110
Scenario 4a	2011	1,057	15,463	120	0.201
	2035	1,067	15,465	120	0.200
Scenario 4b	2011	11,486	102,272	600	0.056
	2035	11,486	102,275	600	0.056
Scenario 4c	2011	7,556	20,786	208	0.033
	2035	7,556	20,784	208	0.033
Scenario 4d	2011	8,600	62,415	490	0.060
	2035	8,617	62,414	490	0.060
Scenario 5	2010	10,275	68,636	467	0.052
	2035	10,280	68,635	481	0.052

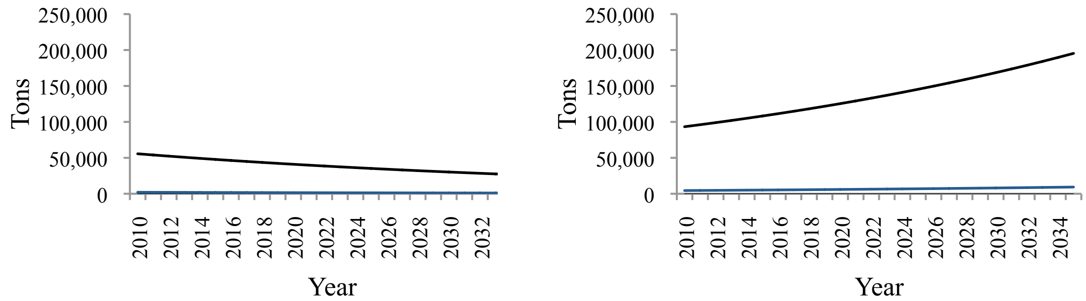
Lower bound describes the amount of material predicted by the model, while the costs and avoided emissions may be higher or lower than those at the higher bound. Negative values (cost savings) are in parentheses.
* Due to different initial years for the policies simulated in each scenario, comparing start values is not exact. Each scenario, with the exception of scenario 5 for which policies are represented as immediately taking effect, is identical to scenario 1 for at least the first year of the simulation.

Table 10. Higher bound normalized cost and avoided emissions estimates for each scenario.

Scenario	First Year Enacted* Final Year	$/avoided MTCE	$/deconstruction job	$/ton diverted	Avoided MTCE/ ton diverted
Scenario 1	2010	0	n/a	0	0
	2035	0	n/a	0	0
Scenario 2	2013	2,731	24,204	47	0.099
	2035	(6)	(65)	0	0.142
Scenario 3	2011	(2,625)	(45,455)	(158)	0.249
	2035	3,577	44,440	215	0.123
Scenario 4a	2011	(2,542)	(41,844)	(268)	0.241
	2035	(2,543)	(41,843)	(268)	0.240
Scenario 4b	2011	16,121	128,559	889	0.061
	2035	16,121	128,558	889	0.061
Scenario 4c	2011	(8,904)	(20,166)	(241)	0.033
	2035	(8,904)	(20,166)	(241)	0.032
Scenario 4d	2011	7,985	48,524	464	0.062
	2035	7,998	48,524	464	0.062
Scenario 5	2010	10,575	57,955	474	0.054
	2035	10,579	57,955	493	0.054

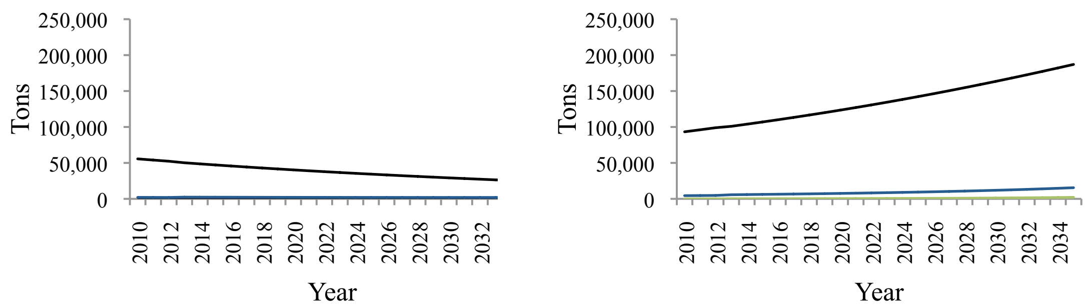
Higher bound describes the amount of material predicted by the model, while the costs and avoided emissions may be higher or lower than those at the lower bound. Negative values (cost savings) are in parentheses.
* Due to different initial years for the policies simulated in each scenario, comparing start values is not exact. Each scenario, with the exception of scenario 5 for which policies are represented as immediately taking effect, is identical to scenario 1 for at least the first year of the simulation.

Figure 2. Scenario 1 C&D management fate tonnage by year.



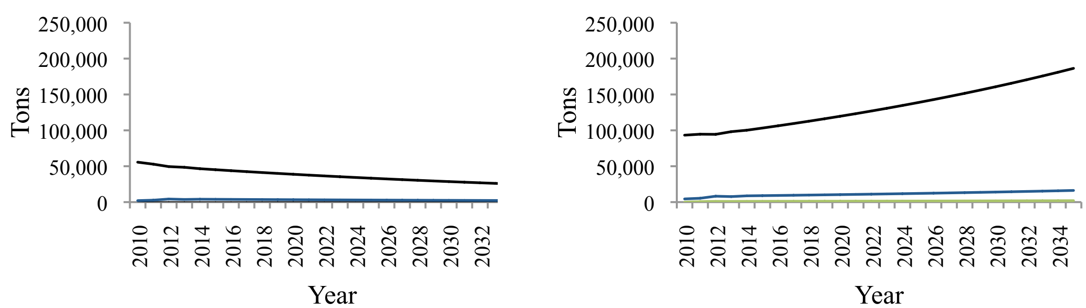
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 3. Scenario 2 C&D management fate tonnage by year.



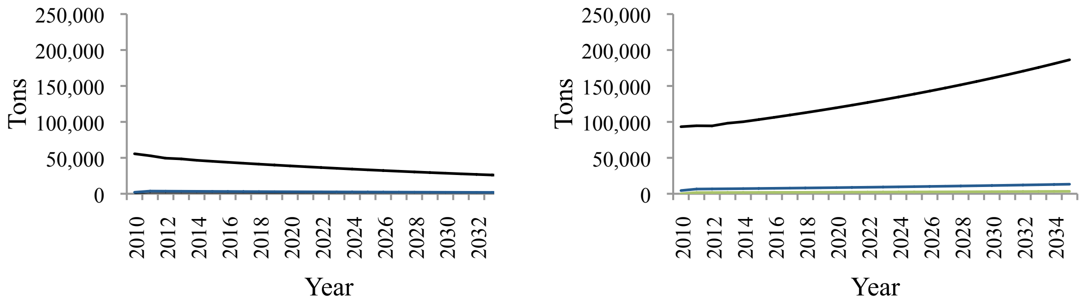
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 4. Scenario 3 C&D management fate tonnage by year.



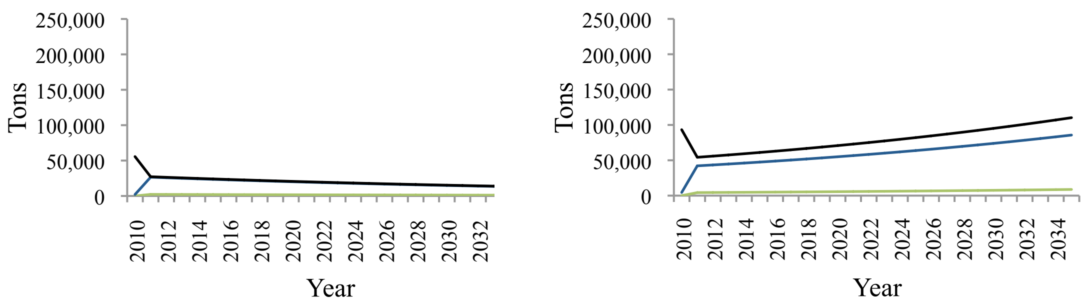
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 5. Scenario 4a C&D management fate tonnage by year.



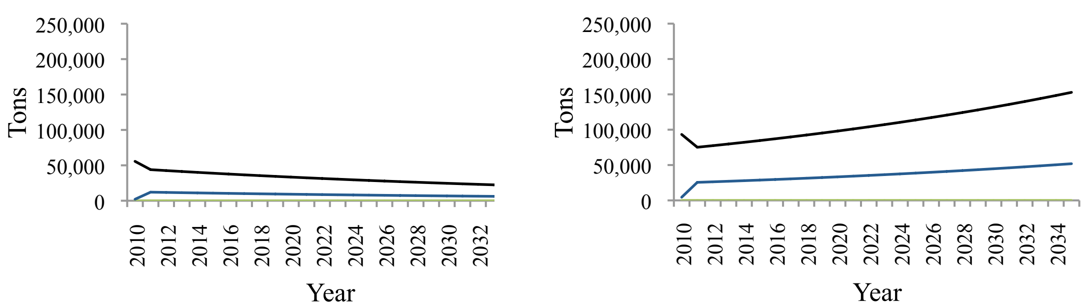
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 6. Scenario 4b C&D management fate tonnage by year.



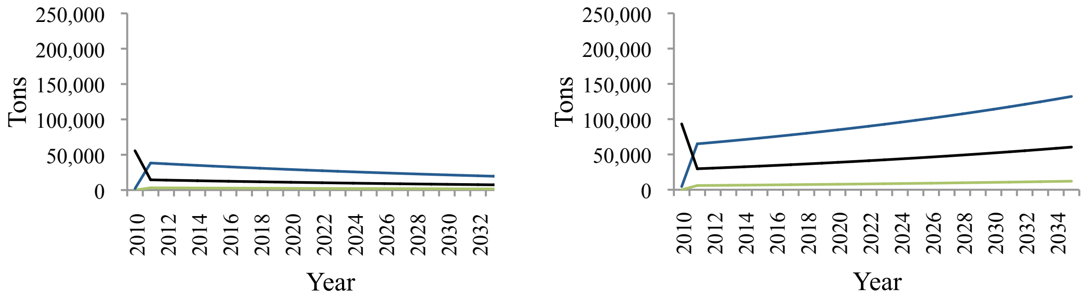
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 7. Scenario 4c C&D management fate tonnage by year.



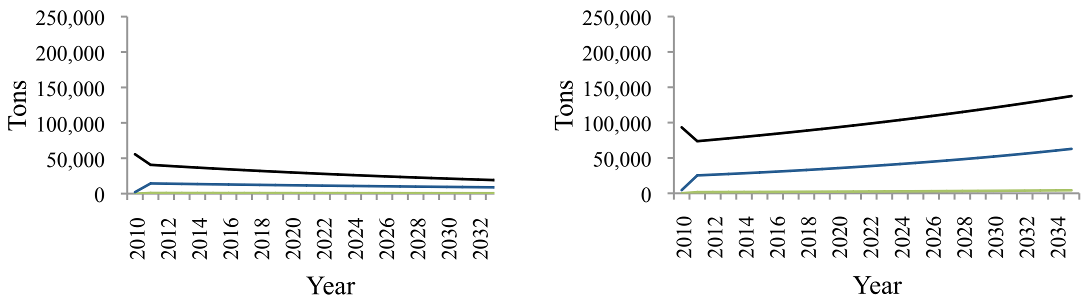
Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 8. Scenario 4d C&D management fate tonnage by year.



Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Figure 9. Scenario 5 C&D management fate tonnage by year.



Lower bound (left graph) and higher bound (right graph). Reuse tonnage is represented by the green line (when present), recycling is represented by the blue line, and landfill is represented by the black line..

Discussion

The results of the model presented here predict that the current amount of C&D generated in the City of New Haven, Connecticut is between 57,715 tons per year and 97,754 tons per year. Depending on growth forecasts for construction activity over the next 25 years, this prediction range grows to between 26,951 tons per year and 204,674 tons per year. These amounts are significantly higher than those reported by the City of New Haven Department of Public Works as the C&D component of municipal solid waste (MSW) and are comparable to the estimates of waste generated by all entities, public and private, in the City as reported by the Connecticut Department of Environmental Protection (CTDEP, 2006). These amounts are also higher than those estimated by Dion (2001).

Using surveys of waste haulers, private waste management firms, the City of New Haven Transfer Station, and the Connecticut Department of Environmental Protection, Dion estimated New Haven generation of C&D to be over 20,000 tons per year in 2001 (Dion, 2001). Using this estimate for comparison here is complicated by the fact that waste haulers and processing facilities in New Haven process waste from outside of New Haven and vice versa.

The total Connecticut C&D figure estimated by the Connecticut Department of Environmental Protection in 2003 was 1.78 million tons per year (CTDEP, 2006). That figure would predict a per capita level of approximately 0.52 tons annually for C&D in Connecticut (CERC, 2010). Given New Haven's population of roughly 124,000 individuals in 2003, the total annual C&D waste stream for New Haven would have been 63,976 tons in that year.

As a general conclusion, C&D is a larger waste stream than has been reported for New Haven and one which will be difficult to control due to the multitude of actors responsible for its generation and management.

Subdividing this waste stream into sources by building type reveals that the two largest sources of C&D in New Haven are commercial and industrial building removal. Commercial is far and away the dominant source of C&D by mass. Industrial buildings make up a large portion of the remainder of the waste stream.

This study yields three important findings about waste management options for C&D in New Haven. First, the most cost effective management option is only the business as usual demolition option if growth in new construction and demolition is very low or negative and if tax deductions from building material donations for reuse are not accounted for. If growth in new construction and demolition in New Haven is positive or very positive over the next 25 years, the most cost effective management options are those utilizing at least some source separation, reuse, and recycling of materials following removal by deconstruction. This is in keeping with costs comparisons revealed in practice between demolition and deconstruction when tax incentives are accounted for.

The tax deductions calculated in the results section above for residential building material donations from deconstruction reveal two modes of accounting for building material donations. Dantata et al. uses estimates of the actual resale value of building materials while Reiff uses appraised values and assumes the top tax bracket (35%) to calculate potential tax benefits of deconstruction and building material resale. As shown above, these two methods reveal two very different ranges of incentives that have important implications for the final cost of deconstruction versus demolition for residential buildings. That deconstruction can often cost less than demolition after tax incentives and can sometimes even provide a net benefit to a property owner helps to explain the literature focus on residential deconstruction and the success of deconstruction for residential buildings in comparison with other building types at present.

Even in the most extreme scenario presented here, 4d, resulting in 70.48% to 74.10% C&D diversion from landfill, total costs for removal and waste management are only between roughly 1.2 and 2 times the current cost depending on construction sector growth forecasts.

The second significant finding is that reducing the amount of C&D sent to landfill from New Haven requires tackling the waste generated in the removal of commercial and industrial buildings. These two sources of C&D waste are deceptively large given the relatively small number of building and demolition permits filed and units added and removed annually of these building types. The mass of these C&D sources also reflects a bias in the management methods of waste towards measuring waste in weight, rather than environmental impact, long-term costs, volume, or another metric.

Third, the environmental impact of waste management options described here and measured in metric tons carbon equivalent (MTCE) is most directly correlated with the mass of materials managed in all but one scenario. Diversion of waste from residential buildings produced higher avoided MTCE emissions than would be expected from the mass of this waste stream due to the reusability of residential materials allowing a greater level of avoided emissions than by recycling alone.

Certainly there are other means of measuring the environmental impact of waste, including eutrophication potential, acidification potential, landfill threats to drinking water supplies, habitat destruction, and many others. This study also took advantage of the partial lifecycle analysis approach utilized by the WARM model to account for avoided emissions from reuse and recycling of materials in place of using virgin materials. While this system boundary for environmental impacts attempts to count total emissions from the time of building removal to the completion of a new building, excluding the emissions from demolition and construction activities, there are many other options for creating a system boundary. Of particular interest would be a study documenting the emissions generated during different types of building removal, given worker travel times and distances, days worked, and methods employed. Another approach, given the cost data presented here, would be to conduct an input-output lifecycle analysis of deconstruction versus demolition methods of building removal and C&D management.

As environmental impacts were described in this study, diverting significant amounts of C&D from landfill would have a significant positive impact. In the best possible case, scenario 4d, between 1,136 and 8,367 MTCE of emissions would be avoided. This total is between roughly 0.23 times and 1.7 times the current level of emissions New Haven avoids by burning MSW for energy rather than landfilling it based on EPA WARM model results calculated from waste data provided by the City of New Haven Office of Sustainability (Zinn, 2010). Simply in the mass of materials that can be diverted from landfill by the removal and source separation techniques utilized for this scenario a significant improvement can be made in New Haven's waste management outlook.

The choice here to report both the mass of waste generated through building removal and renovation activity in New Haven and the emissions levels of different scenarios helps to place this work in the broader discussion of comparing different environmental impacts across sectors and activities. As has been said elsewhere, the energy demand from buildings in their use phase far outweighs the embodied and construction and demolition energy demand (Thormark, 2006). However, when we consider just the emissions from waste management we see that as C&D is responsible for a large part of the total New Haven waste stream if is therefore responsible for a large part of the total emissions from the management of that waste stream.

It is important to note that the emissions and diversion figures presented here rely on strong assumptions in the model. Those include the assumptions that certain materials which are not currently able to be recycled in or near New Haven will continue to be landfilled over the next 25 years, such as interior drywall and miscellaneous debris. Improved source separation and the introduction of new types of recycling facilities to the New Haven area could alter these assumptions and improve the overall diversion potential for C&D in this location. The assumptions in this model also assume that some materials, such as industrial structural masonry, are always recycled rather than reused. This assumption is based on the current residential focus of deconstruction in practice and on the difficulty of removing a masonry structure by hand while maintaining the integrity of the materials removed (Reiff, 2010a). Again, improvements in technique could alter this assumption so that a much larger portion of C&D could be reused and thereby produce even fewer emissions in its management, but for the purposes of this model, this was deemed unlikely.

Yet another assumption contained in this model concerns materials intended for reuse or recycling but rejected. This model assumes that the rate of materials rejection from reuse or recycling is not different from zero. Future iterations of this work should take into account both rejection of materials for reuse and a learning curve or improvement in source separation technique on the building removal site to investigate how contamination of reuse and recycling streams can affect final diversion rates.

Perhaps the most important assumption in this model is that none of the policies described in the above scenarios affect the growth or decline in the market for removing buildings. The same building area is expected to be removed regardless of the policy enacted. A solid economic model for changes in price and demand in building removal is needed to correct for this assumption.

An alternative approach to that taken here might have addressed materials generated through building demolition by studying building lifetimes and predicting building removal according to end-of-life assumptions. However, not only is a good demography of the building population in New Haven missing for this approach, but the variability in building lifetime before removal is expected to be very great within and between building type groups as a result of the old age of New Haven's building stock relative to other cities in the United States.

A preferable metric, that was used here, is actual building removal in a given year that can be correlated to new building construction in the same year. We might have expected a "one in, one out" scenario in a dense urban area in which any new building necessitated the removal of an old building. However, what was observed was a greater amount of building removal than new construction for residential utility and commercial buildings and a lower level of removal than new construction for residential and industrial buildings. This indicates that the total building stock for residential utility and commercial buildings is shrinking while residential and industrial building stock is growing. This study takes these results as a snapshot in time and projects them as constants (within a range of uncertainty) over 25 years but in reality the rate of growth or decline in building stocks by building type is likely to change over time. Future studies should address this dynamic in creating predictive models for building removal in urban areas.

Comparing these results to others in the literature is limited by the broad focus here on all building types in one small city versus other author's conclusions largely about individual residential buildings or small groups of buildings only. However, we can consider the results of this study, in particular scenario 5, in light of alternative C&D materials management ordinances proposed or enacted in other municipalities.

While some municipalities have taken the approach of requiring minimum diversion rates, others have required detailed waste management plans for building removal sites to be approved by building officials, and yet others have simply banned certain waste types from solid waste landfills. Each of these alternatives should be tested in future studies for New Haven to compare with the results here.

While those requiring management plans and strongly recommending "on-site processing or source separation for recycling or reuse" but not requiring diversion rates, there is much room for interpretation and avoiding such direction (Half Moon Bay, 1999). Where diversion rates are enforced, measures must be taken to ensure that heavy inert materials such as foundations are excluded from diversion rates or have their own diversion rate requirements as their mass would make up all or a large portion of the required diversion for any given project resulting in landfill disposal of more valuable and inherently reusable products such as wood and fixtures (County of San Mateo, 2002).

An interesting approach is that taken by the State of Massachusetts simply banning asphalt pavement, brick, concrete, metal, and wood from solid waste landfills (MADEP, 2010). Focusing on product-driven regulation streamlines processing procedures at recycling facilities and allows for removal contractors to take advantage of the most cost and time effective methods for a given project while regulators can more easily monitor waste streams at a few sites within the state. This regulation has already led to the rapid expansion of the building material recycling industry in Massachusetts, because recycled materials can be sold at a profit following processing, creating additional jobs and income from what had formerly been strictly a waste management cost to property owners (Seldman, 2010). From the results presented here, it is clear that a study of a hypothetical waste ban along these lines in New Haven would provide a significant diversion improvement from the current C&D regime.

In addition to the suggestions for future study mentioned above, the most important expansion of this work will be to additional cities. While we would expect these results to be applicable to cities with similar building stock and economic circumstances to New Haven, in the absence of further studies it is difficult to make such claims definitively. Following studies of cities similar to New Haven, this work should expand to cities with different building types, growth or decay projections, and available management options in creating policy tools for improving the environmental impact, costs, and jobs available through building removal techniques. A thorough spatial survey of building materials available for recycling and reuse for cities would also be an invaluable resource for future work.

Conclusion

This study provides an answer to the question of whether or not alternative building removal and C&D materials management techniques such as deconstruction with reuse and recycling can provide a solution to the related problems of large amounts of C&D waste going to landfill and large amounts of new material being imported for construction purposes. This study also describes the most effective diversion options for C&D waste and the most cost effective of those options given the current policies being considered by the City of New Haven. Far from being unimportant, the policy chosen to regulate the flow of building materials from building removal will have major consequences for the success of efforts to reduce waste being sent to landfills, the emissions associated with C&D, the cost of removing buildings and managing C&D, and the jobs created by deconstruction of all or some of the buildings removed in New Haven.

Policy makers can test out their own scenarios for building removal options using the downloadable version of the model described above. (Instructions for download and use appear in Appendix A.) While the results of the scenarios presented here are given as a wide range of estimates reflecting uncertainty in the future, policy makers can run scenarios based on their own expectations for future new construction and deconstruction rates for example, as well as other variables represented in the model.

For example, if we expect that the roughly 0% growth in new construction in New Haven between 1996 and 2009 will hold for the next 25 years, we can set the new construction parameter to 0% and run different management scenarios. With 0% growth in new construction and mandated deconstruction of all residential and residential utility buildings, the model estimates that the rate of diversion from landfill will be roughly 8%. If we assume a 1% growth in new construction however, that 8% rate could grow to over 10% in 25 years – still not a large fraction of the total C&D leaving New Haven.

In another example, if we assume 1% growth in new construction and deconstruction of all commercial buildings, we would expect the diversion rate to be between 46% and 51% in 2011 and between 59% and 66% in 2035 – a vast improvement over the current situation.

Costs, jobs created, and emissions are all likewise modeled according to the users assumptions and expectations for the future.

In general, deconstruction with reuse and recycling will not fully eliminate the C&D waste stream destined for landfill nor will reused materials replace a significant portion of new construction materials by mass. Some portion, potentially a significant portion by mass, of every building currently in the New Haven building stock must be disposed of through landfill or combustion for energy recovery and then landfill. As design for deconstruction concepts gain hold in the design and construction of buildings this may change, but we are not there yet. Recycling of a large portion of building materials does, however, provide an intermediate solution to the joint problems of waste and new material consumption by circumventing part of the landfill-bound waste stream and part of the new material input. In terms of quantity of building materials by mass in New Haven, their types and current processing facilities, recycling a higher portion of inert heavy wastes such as foundation concrete and structural masonry is a good beginning to reducing the impact of building removal and new construction.

Due to the nature of the majority of the mass of C&D originating in New Haven, reuse will only make up a small portion of any diversion plan. The sheer mass of most of the material that cannot be reused precludes a significant level of reuse by mass. This is not to say that reuse is not the environmentally or economically preferable option – it is. Rather, it will remain a small part of the diverted stream of C&D.

The most effective scenario for diverting C&D from landfill described above is scenario 4d, in which all building types are deconstructed and only those wastes that cannot be recycled or reused are sent to landfill. This solution is much more costly than the current demolition regime in New Haven. The lowest cost scenario described above is 4a, assuming a tax incentive for property owners, in which all residential and residential utility buildings are deconstructed. At the model's upper bound for construction activity growth, and not assuming tax incentives for residential property owners, scenario 4c, in which all industrial buildings are deconstructed, is the lowest cost option.

Both scenarios 4a and 4c provide a savings over current demolition practices if we assume a small annual growth in construction and removal activity in terms of cost per ton of material diverted, cost per avoided MTCE, and cost per job created. Scenario 4a provides a slightly higher savings in terms of cost per avoided MTCE and job creation and scenario 4c provides a higher savings in terms of cost per ton of diversion. If negative growth in construction and removal activity is observed, the BAU scenario provides the lowest cost, although the benefits of deconstruction job creation, diversion, and avoided emissions would not be realized in that case. Scenario 3, in which the City of New Haven sequentially adds categories of buildings it owns to those it deconstructs, provides an initial cost savings with residential buildings, but as commercial buildings are added to the scenario, costs quickly rise.

If cost is not the only consideration, and diversion, emissions, and job creation are considered, this study recommends adopting scenario 4d (total deconstruction) as the best option followed by scenario 4b (commercial deconstruction) and then scenario 5 (the New Haven Green Building Policy draft as currently worded). Each of these scenarios puts pressure on the building category responsible for the largest amount of waste in New Haven, commercial buildings – a category which includes educational buildings – and on the businesses and institutions removing that building type. Any policy option which does not require alternative disposal methods for commercially-generated C&D will fall short of goals to significantly reduce landfilling of New Haven's C&D, reduce emissions, and create jobs.

If cost is given greater weight, this study recommends adopting both scenario 4a and scenario 4c, requiring deconstruction of residential, residential utility, and industrial buildings. This option would come at a cost savings to those engaged in building removal, reduce significantly the landfilling of C&D and associated emissions, and would create many jobs. Although this option would still result in the majority of New Haven's C&D waste stream being sent to landfill, it would also be a marked improvement over BAU over the next 25 years.

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Appendices

Appendix A. Model Availability, Audience, and Use

The dynamic systems model presented here is available for download and use at the http://www.yale.edu/hixon/research/sri.html. The intended audience for this model is City of New Haven officials and policy makers as well as officials in other small northeastern cities with building stocks similar in character and age to New Haven, Connecticut.

The majority of underlying assumptions concerning mass of materials per square foot and fate of materials removed by deconstruction versus demolition made in this study are held constant in the model and most processes are locked out. However, model users can input a variety of variables and assumptions about the building construction and removal systems in their communities and different outlooks for the future. Model output is limited to 25 years. The model is most accurate for cities with out-of-state landfill destinations for C&D waste.

The variables controlled by the model user are: initial square feet of new construction in the reference year, ratio of new commercial, industrial, and residential utility square feet to residential square feet, ratio of removal to new construction for each building type, ratio of rehabilitation to new construction, the fraction of buildings removed by deconstruction, the presence or absence of a reuse facility in the city being modeled, the total price per square foot for demolition, the labor cost for deconstruction, the cost of abatement, and the weight of fixtures removed per square foot building removal. The model is run in one-year increments to allow variation in these inputs at the user's discretion.

The model output is a set of tables and graphs displaying the following: square feet of buildings added and removed annually by building type and in total, tons of building material managed, tons of building material landfilled, tons of building material reused, tons of building material recycled, total diversion rate, total MTCE emitted, total cost, deconstruction jobs created, cost per ton of material diverted, cost per avoided MTCE emitted, and cost per deconstruction job created.

Appendix B. Model Structure

The overall organization of the model comes out of a disaggregated group of building material calculators for new construction and removal organized by material type and incorporating each relevant building type stock and flow for that material. The main driver for these calculators is a set of converters that determines from the square feet of new residential construction the annual rate of new residential utility construction, new commercial construction, and new industrial construction. From these rates, using conversion factors discussed in Appendix E, and the ratio of square feet rehabilitation to new construction, annual rates of removal by building type are calculated. Along with conversion factors discussed in Appendix C, the new construction rates determine the annual increase in the stock of each building material, and the removal rates determine the annual removal from the stock of each building material. A set of converters dictating the fraction of both methods of material removal (demolition versus deconstruction) employed by building type determines the fate of removed material – whether it be landfilled, recycled, or reused. Also discussed in Appendix C is the method by which removed material for reuse offsets new material to be used for new construction within or outside of New Haven.

Two model subsections, the Materials and Environmental Summary and the Economic Summary, provide an accounting of the annual material added and removed from the New Haven building stock for each material type, the fate of the removed material, and the MTCE emissions resulting from the different waste management fates, the cost of building removal, and the deconstruction jobs created by building type, and by fate.

The conversion factor values for construction, removal, and deconstruction versus demolition are presented in the Materials and Methods and Results Section and in Appendix E. The Materials and Environmental Summary and Economic Summary conversion factors and the values numbers not reported elsewhere are reported below (Table b1, Table b2). Tipping fees, container, and hauling costs were calculated using average cost per ton for those services in New Haven (MGM Carting, 2010) and the average tonnage of each material type per square foot of building type calculated for the model for 2010 (Appendix C) for each material's disposal fate. Profit, supplies and overhead were assumed to be calculated as 40% of soft costs (Reiff, 2010a).

For the WARM model results, the current mix of virgin and recycled materials was assumed for source reduced materials, the national average for landfill gas recovery was assumed at the national average efficiency, the landfill was assumed to be in Cleveland, Ohio (Baldwin, 2010). 537 miles from New Haven, Connecticut, the incineration facility and recycling faciltities were assumed to be in New Haven at a distance of 3 miles from the hypothetical project site, and the composting facilitiy was assumed to be in Milford, Connecticut (Zinn, 2010) 10 miles from the hypothetical site. Negative emissions values result from avoided emissions from reuse and recycling, and from the increase in landfill carbon stocks over time for organic matter that does not fully decompose in landfill (EPA, 2009).

Table b1. EPA WARM Model emissions results by material type and fate.*

Material	Landfill (MTCE/ton)	Recycling (MTCE/ton)	Reuse (MTCE/ton)	Most Similar WARM Model Category
Composition Shingle	0.030	(0.003)	-	Concrete
Shake Shingle	(0.115)	(0.670)	-	Dimensional Lumber
Membrane Roofing (EPDM)	0.030	(0.417)	-	Mixed Plastics
Clapboard Siding	(0.115)	-	(0.551)	Dimensional Lumber
Vinyl Siding	0.030	-	(0.417)	Mixed Recyclables
Masonry Siding	0.030	(0.003)	(0.078)	Clay Bricks (reuse) Concrete (recycling)
Interior Drywall	0.030	-	-	Fly Ash
Interior Plaster	0.030	-	-	Fly Ash
Wood Flooring	(0.115)	-	(0.551)	Dimensional Lumber
Wood Framing	(0.115)	-	(0.551)	Dimensional Lumber
Plywood Sheathing	(0.115)	-	-	Medium-Density Fiberboard (MDF)
Steel Framing	0.030	(0.491)	-	Steel Cans
Structural Masonry	0.030	(0.003)	(0.078)	Clay Bricks (reuse) Concrete (recycling)
Concrete Foundation	0.030	(0.003)	-	Concrete
Fixtures	(0.006)	-	(0.442)	Glass, Steel Cans, MDF (10:5:5 ratio)
Miscellaneous Debris	0.430	-	-	Mixed MSW

*Missing values indicate disposal fates currently not available or assumed to be unavailable in New Haven at present for a given material type or, in the absence of a value for reuse, those materials for which recycling is preferable to reuse due to feasibility and the opposite in the absence of a value for recycling. These fates are never assigned to those materials as they are generated in the model. Negative values appear in parentheses.

Table b2. Deconstruction tipping fees, container, and hauling costs and hardscape removal costs.

Building Type	Tipping Fees, Container, and Hauling Costs ($/ft^2)	Mechanized Hardscape Removal Costs ($/ft^2)
Residential	5.48	2.46
Residential Utility	3.98	1.54
Commercial	6.39	2.72
Industrial	4.89	2.03

Appendix C. Model Substructure

The disaggregated material calculators that make up the backbone of this model use building type-specific conversion factors for each material to calculate the tonnage of each material added to or removed from the New Haven building stock each year.

When deconstruction with reuse in New Haven is enabled for all or a fraction of a material removal flow, that material offsets new material that would otherwise make up part of the flow of material added to the building stock in that year. Reused material is allowed to comprise up to 100% of the new material flow, and any excess is diverted to the extra New Haven flow for that material as it is assumed to be used outside of New Haven in that year rather than stockpiling. When deconstruction with material reuse is enabled but New Haven reuse is not enabled (due to lack of a New Haven material reuse warehouse or store), all reusable material is assumed to be reused outside of New Haven.

Where more than one building type is enabled to reuse material generated through deconstruction, each building type receives a share of the reused material proportional to the total new material demanded for that building type in new construction in that year up to the total new material demanded.

The rate at which removed material moves out of the building stock is determined by the building removal for each building type and the percentage of removed material destined for different disposal fates is determined by the percent of removal by demolition versus deconstruction for each building type. Due to the complexity of these interdependent flows, nearly all entities in each material calculator are in communication with one another.

A graphical representation of a simple (Figure c1) and a more complex (Figure c2) material calculator appear below. As material stocks serve as placeholders for material added to or subtracted from the New Haven building stock in a given year, they are allowed to be negative should removal exceed new construction in that year. In this sense they do not represent the total New Haven building stock, which is assumed to be much larger than the sum of the stocks in the model and which would allow for removal at a rate exceeding new construction in any given year. Model equations are found in Appendix E.

There are 16 materials represented in the model in total. The conversion factors describing tons of material per square foot of building removal by building type are listed below (Table c). These conversion factors derive from calculations of building material weight by volume for each building material and volume estimates made for a hypothetical building that represents the average building size for each building type of those removed in 2010. Material weights were derived from the literature (Falk and Guy, 2007) and from a deconstruction training and building materials estimation course (Reiff, 2010a). This produces an estimate of tons per square foot for each material and building type which rest on assumptions about building construction techniques made from the author's experience working in construction and building removal in New Haven during the summers of 2009 and 2010 and material volume and mass calculations described by Rieff (2010). Footprint, height, floor area, and total volume were known for all buildings removed in New Haven in 2010.

Some of the materials are assumed to be found in some examples of a building type but not others as building type is often determined by ownership and houses in New Haven are sometimes converted to businesses. For instance, some commercial buildings in New Haven are wood frame structures with vinyl siding not different in their construction from a typical residential building. Likewise, some residential buildings have wood siding while others have vinyl siding. In the absence of a thorough survey of New Haven's building stock by material type, some assumptions are made about the proportion of each building type removed that contains a given material. These proportions are likely to change through time and a thorough, updated survey of New Haven's building stock will be required to make more precise estimates than those presented here.

Those assumptions for removed buildings are as follows: based on the age of New Haven residences, 50% of residential buildings are assumed to have shake shingles under composition shingles; membrane roofing is assumed to consist of two layers of membrane; 50% of residential and residential utility buildings are assumed to have clapboard siding and 50% of these buildings are assumed to have vinyl siding; 50% of commercial buildings are assumed to have vinyl siding and 50% are assumed to have masonry siding; 50% of residential buildings are assumed to have interior drywall and 50% are assumed to have interior plaster; 100% of commercial buildings are assumed to have drywall; 50% of commercial buildings are assumed to have composition shingle roofing and 50% are assumed to have membrane roofing; 50% of commercial buildings are assumed to have wood framing and 50% are assumed to have structural masonry and steel framing; all industrial and residential utility buildings are assumed to have slab foundations rather than full basements.

The amount of material generated during building removal by building type as calculated for this model compares favorably with those reported for one other municipality which confirm the calculations for each material type described above. Contra Costa County estimates that residential buildings produce 0.0557 tons per square foot in their removal and that nonresidential buildings produce 0.0775 tons per square foot in their removal (Contra Costa, 2010). The results calculated here are an average of 0.0512 tons per square foot for commercial buildings, 0.0383 tons per square foot for industrial buildings, 0.0464 tons per square foot for residential buildings, and 0.0291 tons per square foot for residential utility buildings.

Figure c1. Fixture material calculator. Stocks are rectangles, flows are arrows with a circle at their center, and converters (conversion factors) are circles. Red arrows denote where information is shared between model entities. Clouds represent stocks outside the model boundaries.

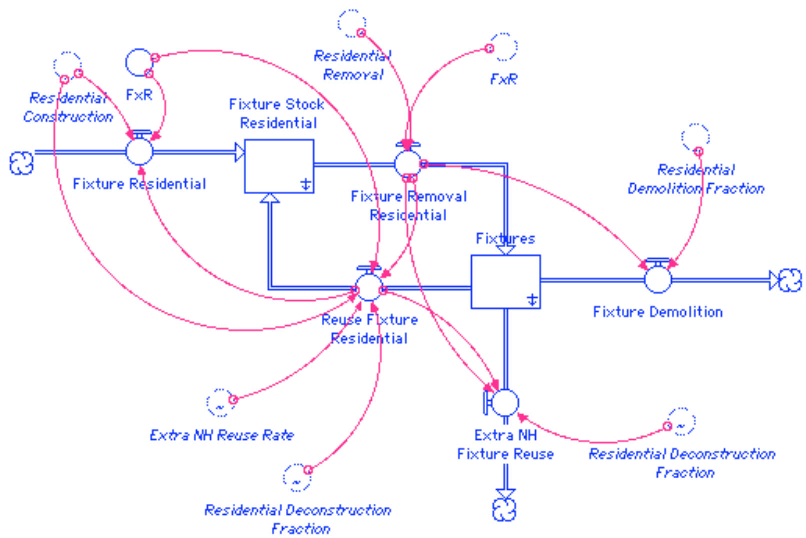

Figure c2. Vinyl siding material calculator. Stocks are rectangles, flows are arrows with a circle at their center, and converters (conversion factors) are circles. Red arrows denote where information is shared between model entities. Clouds represent stocks outside the model boundaries.

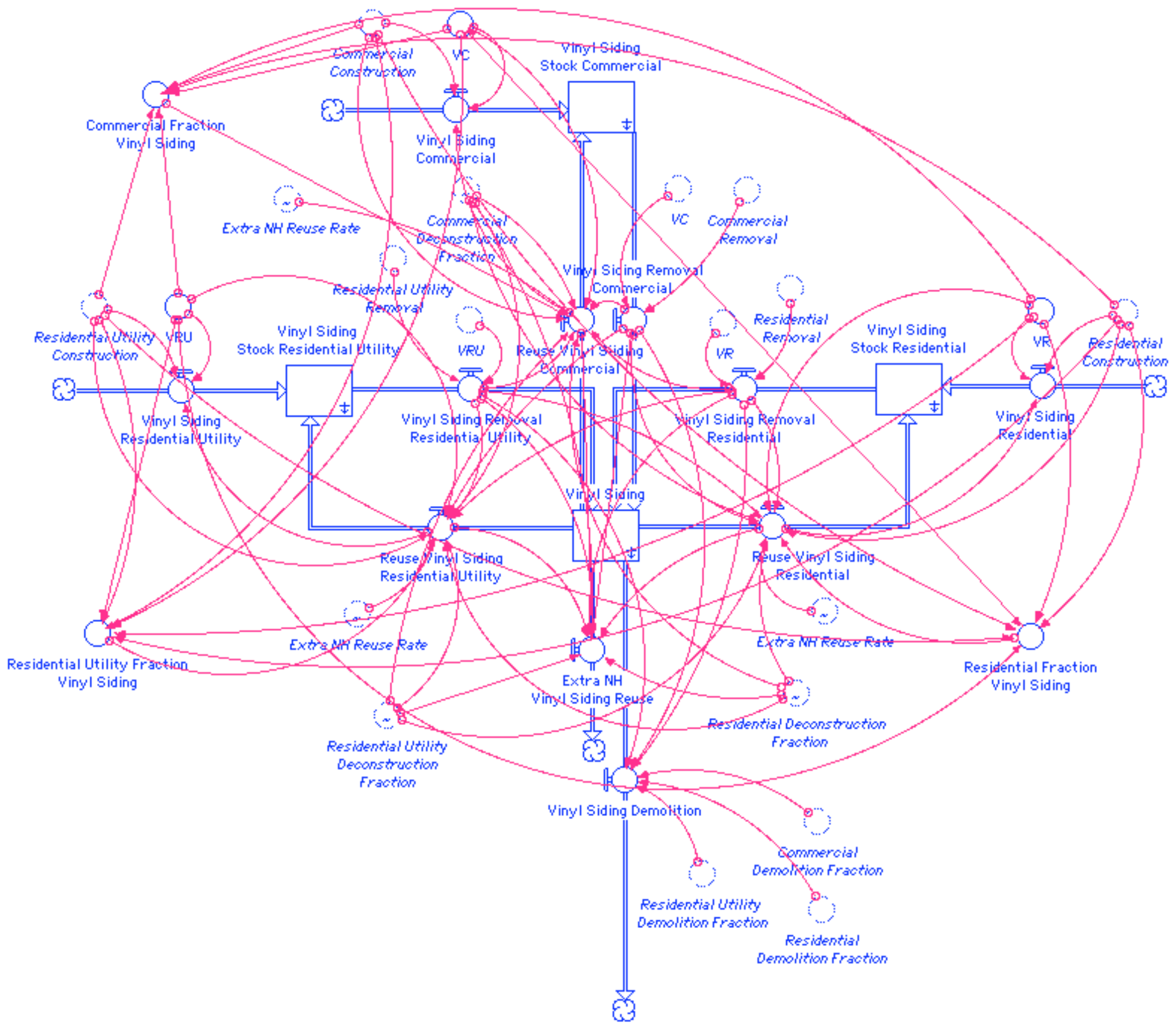

Table c. Conversion factors for each building material and building type.

Material	Residential (t/ft^2)	Residential Utility (t/ft^2)	Commercial (t/ft^2)	Industrial (t/ft^2)
Composition Shingle	0.0008	0.0025	0.0004	-
Shake Shingle	0.0010	-	-	-
Membrane Roofing (EPDM)	-	-	0.0006	0.0027
Clapboard Siding	0.0005	0.0003	-	-
Vinyl Siding	0.0001	0.0002	0.0001	-
Masonry Siding	-	-	0.0011	0.0010
Interior Drywall	0.0020	-	0.0024	-
Interior Plaster	0.0036	-	-	-
Wood Flooring	0.0015	-	-	-
Wood Framing	0.0031	0.0031	0.0016	-
Plywood Sheathing	0.0008	0.0015	0.0002	-
Steel Framing	-	-	0.0010	0.0021
Structural Masonry	0.0004	-	0.0110	0.0100
Concrete Foundation	0.0265	0.0152	0.0269	0.0165
Fixtures	*	-	-	-
Miscellaneous Debris	0.0060	0.0060	0.0060	0.0060
Total	0.0464	0.0291	0.0512	0.0383

*See appendix E for the values of this sensitivity variable.

Appendix D. Sensitivity Testing

The extreme bounds of the model for each time period were found by identifying variables with high uncertainty and a known range of values and grouping those variables into cost and area and mass categories. Combining low and high cost possibilities and low and high area and mass possibilities yielded four combinations of cost with area and mass as generated by the model. For the results presented above, the model was run twice for each scenario, once with the low price, low area and mass combination and once with the high price, high area and mass combination. In this way, the expected real result is somewhere between these two extreme frontiers.

The range for each of the sensitivity variables is presented below (Table e). New residential construction growth is discussed in the Results section above. The rehabilitation ratio was calculated assuming that the average rehabilitation is between roughly 5% and 7% the area of a removed building.

The ratios of new construction area of building types to residential building area were calculated in two ways. In the first, the number of new construction permits for each building type for 2010 was multiplied by the average removed building area by type for 2010 which assumes that only residential buildings grow in area on average each year, and this area was divided by the new residential area for 2010. In the second, building area growth for 2010 was estimated using the ratio of average building area by type to average residential building area for buildings removed in 2010 and by multiplying this higher average by the number of new construction permits for each building type. The ratio of this total building area by type to new residential building area was then calculated. The ratio of building removal to new construction was calculated using the known area of buildings removed by type in 2010 and the two different new construction area estimates above. The higher value for removal ratio is lower than the lower value because it corresponds to a greater area of new construction in relation to the same amount of known removal for 2010. Fixture estimates came from two sources, the Case Study described above provided the low estimate and records from the deconstrution of a high-end house in Greenwich, CT provided the high estimate (Mike Yurish, TRP). These estimates were in the form of descriptive lists of products removed for resale, from which weights were estimated using conversion factors from an external source (resource management group).

Abatement and demolition costs came from a study conducted by the City of New Haven Office of Economic Development Small Business Construction Program in the Summer of 2010 that surveyed average demolition costs per square foot for a range of residential projects in the

City (Snyder, 2010b). These costs were then adjusted for the other three building types using the ratio of average tons generated per square foot of building removal by building type to tons generated per square foot of building removal for residential buildings assuming that costs relate most closely to tons of material handled.

Deconstruction labor rate was the only variable that differed between the high and low estimates of deconstruction cost by building type and is therefore accounted for in the deconstruction costs presented below. The other components of deconstruction cost – tipping fees, container rental, hauling, and mechanized hardscape removal are presented on a ton per square foot basis for each building type in Appendix B. The lower deconstruction labor rate was calculated for the Case Study house using five laborers and one supervisor at four different wage levels and taking the weighted average of those rates per hour and using the average deconstruction rate in hours per square foot for that project to calculate the cost per square foot which was $3.80. The higher deconstruction labor rate came from Dentata et al., presented as a cost per square foot of $14.09, and assumed a Massachusetts average construction laborer rate of $31.30 per hour (Dentata, 2005).

Those model variables that had low uncertainty or a completely unknown range of values were excluded from the sensitivity parameters. Low uncertainty variables originated from empirical research and interviews (as described in Appendix C) and included the following: average removed residential, residential utility, commercial, and industrial building size in 2010; disposal, clean wood, clean fill, asphalt shingle, and metal container, hauling, and tipping fee cost per ton; reuse lumber, brick, and fixture truck rental cost; mechanized hardscape removal cost per square foot of building area; the rate of building removal by deconstruction laborers; and the rate per dollar of removal project cost for profit, supplies, and overhead.

Those model variables that were highly uncertain but unable to be predicted from the work done for this study were also excluded from sensitivity analysis. Instead, a value was assigned to these variables as described in Appendix C above. Highly uncertain variables concerned some of the material composition of included: percent of residential buildings with a shake shingle roof under layer; percentage of residential buildings with clapboard siding, percent of residential buildings with vinyl siding; percent of commercial buildings with vinyl siding; percent of commercial buildings with masonry siding; percent of residential buildings with interior drywall; percent of residential buildings with interior plaster and lath; percent of commercial buildings with wood framing; and the percent of commercial buildings with steel framing and structural masonry.

Table d. Low and high cost and area and mass sensitivity variable combinations.

Variable	Low Value	High Value
New Residential Construction Growth Rate (%/year)	-3.00	3.00
Rehabilitation Ratio to New Construction	1.17	1.68
Residential Utility to Residential Area Ratio	0.03	0.05
Commercial to Residential Area Ratio	1.00	1.76
Industrial to Residential Area Ratio	1.48	2.59
Residential Removal to New Construction Ratio	0.47	0.47
Residential Utility Removal to New Construction Ratio	2.00	1.14
Commercial Removal to New Construction Ratio	2.80	1.59
Industrial Removal to New Construction Ratio	0.75	0.43
Fixtures (t/ft^2)	0.0003	0.0017
Residential Abatement ($\$/ft^2$)	2.49	10.67
Residential Utility Abatement ($\$/ft^2$)	1.56	6.69
Commercial Abatement ($\$/ft^2$)	2.75	11.79
Industrial Abatement ($\$/ft^2$)	2.06	8.81
Residential Demolition ($\$/ft^2$)	10.69	36.06
Residential Utility Demolition ($\$/ft^2$)	6.70	22.61
Commercial Demolition ($\$/ft^2$)	11.82	39.86
Industrial Demolition ($\$/ft^2$)	8.82	29.76
Residential Deconstruction ($\$/ft^2$)	15.60	28.16
Residential Utility Deconstruction ($\$/ft^2$)	12.59	25.02
Commercial Deconstruction ($\$/ft^2$)	17.14	29.70
Industrial Deconstruction ($\$/ft^2$)	14.35	26.91

Appendix E. Model Equations

Below are the equations in the model for the baseline scenario, scenario 1. Stocks have a (t), for tons, following their titles. Conversion factors (described in Appendix C) appear in all caps. Those factors that being with 'W' are metric ton carbon equivalent emissions rates per ton material calculated using the EPA WARM model. Factors beginning with 'E' are metric ton carbon equivalent emissions for each material calculated in this model. Alternate equations for the other scenarios appear further below.

Scenario 1

Main Model Stocks and Flows:

*Clapboard_Siding(t) = Clapboard_Siding(t - dt) + (Clapboard_Siding_Removal_Residential_Utility + Clapboard_Siding_Removal_Residential - Reuse_Clapboard_Siiding_Residential - Reuse_Clapboard_Siding_Residential_Utility - Clapboard_Siding_Demolition - Extra_NH_Clapboard_Siding_Reuse) * dt*
INIT Clapboard_Siding = 0

INFLOWS:
*Clapboard_Siding_Removal_Residential_Utility = CRU*Residential_Utility_Removal*

*Clapboard_Siding_Removal_Residential = Residential_Removal*CR*

OUTFLOWS:
*Reuse_Clapboard_Siiding_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (CR*Residential_Construction) > ((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction) +(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) THEN Residential_Fraction_Clapboard_Siding*((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) ELSE Residential_Fraction_Clapboard_Siding*(CR*Residential_Construction)*

*Reuse_Clapboard_Siding_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (CRU*Residential_Utility_Construction) > ((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction) +(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) THEN Residential_Utility_Fraction_Clapboard_Siding*((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) ELSE Residential_Utility_Fraction_Clapboard_Siding* (CRU*Residential_Utility_Construction)*

*Clapboard_Siding_Demolition = (Clapboard_Siding_Removal_Residential*Residential_Demolition_Fraction)+(Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Demolition_Fraction)*

*Extra_NH_Clapboard_Siding_Reuse = ((Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction))-Reuse_Clapboard_Siding_Residential_Utility-Reuse_Clapboard_Siiding_Residential*

*Clapboard_Siding_Stock_Residential(t) = Clapboard_Siding_Stock_Residential(t - dt) + (Reuse_Clapboard_Siiding_Residential + Clapboard_Siding_Residential - Clapboard_Siding_Removal_Residential) * dt*
INIT Clapboard_Siding_Stock_Residential = 0

INFLOWS:
*Reuse_Clapboard_Siiding_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (CR*Residential_Construction) > ((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) THEN Residential_Fraction_Clapboard_Siding*((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) ELSE Residential_Fraction_Clapboard_Siding*(CR*Residential_Construction)*
*Clapboard_Siding_Residential = (Residential_Construction*CR)-Reuse_Clapboard_Siiding_Residential*

OUTFLOWS:
*Clapboard_Siding_Removal_Residential = Residential_Removal*CR*

*Clapboard_Siding_Stock_Residential_Utility(t) = Clapboard_Siding_Stock_Residential_Utility(t - dt) + (Reuse_Clapboard_Siding_Residential_Utility + Clapboard_Siding_Residential_Utility - Clapboard_Siding_Removal_Residential_Utility) * dt*
INIT Clapboard_Siding_Stock_Residential_Utility = 0

INFLOWS:
*Reuse_Clapboard_Siding_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (CRU*Residential_Utility_Construction) > ((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) THEN Residential_Utility_Fraction_Clapboard_Siding*((Clapboard_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Clapboard_Siding_Removal_Residential*Residential_Deconstruction__Fraction)) ELSE Residential_Utility_Fraction_Clapboard_Siding*(CRU*Residential_Utility_Construction)*

*Clapboard_Siding_Residential_Utility = (Residential_Utility_Construction*CRU)-Reuse_Clapboard_Siding_Residential_Utility*

OUTFLOWS:
*Clapboard_Siding_Removal_Residential_Utility = CRU*Residential_Utility_Removal*

*Composition_Shingle_Roofing(t) = Composition_Shingle_Roofing(t - dt) + (Compostition_Shingle_Removal_Residential + Composition_Shingle_Removal_Residential_Utility + Composition_Shingle_Removal_Commercial - Composition_Shingle_Demolition - Composition_Shingle_Recycling) * dt*

INIT Composition_Shingle_Roofing = 0

INFLOWS:
*Compostition_Shingle_Removal_Residential = Residential_Removal*CSR*

*Composition_Shingle_Removal_Residential_Utility = Residential_Utility_Removal*CSRU*

*Composition_Shingle_Removal_Commercial = Commercial_Removal*CSC*

OUTFLOWS:
*Composition_Shingle_Demolition = (Composition_Shingle_Removal_Commercial*Commercial_Demolition_Fraction) + (Composition_Shingle_Removal_Residential_Utility*Residential_Utility_Demolition_Fraction)+ (Compostition_Shingle_Removal_Residential*Residential_Demolition_Fraction)*

*Composition_Shingle_Recycling = (Composition_Shingle_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Composition_Shingle_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Compostition_Shingle_Removal_Residential*Residential_Deconstruction__Fraction)*

*Composition_Shingle_Roofing_Stock_Commercial(t) = Composition_Shingle_Roofing_Stock_Commercial(t - dt) + (Composition_Shingle_Roofing_Commercial - Composition_Shingle_Removal_Commercial) * dt*
INIT Composition_Shingle_Roofing_Stock_Commercial = 0

INFLOWS:
*Composition_Shingle_Roofing_Commercial = Commercial_Construction*CSC*

OUTFLOWS:
*Composition_Shingle_Removal_Commercial = Commercial_Removal*CSC*

*Composition_Shingle_Roofing_Stock_Residential(t) = Composition_Shingle_Roofing_Stock_Residential(t - dt) + (Composition_Shingle_Roofing_Residential - Compostition_Shingle_Removal_Residential) * dt*
INIT Composition_Shingle_Roofing_Stock_Residential = 0

INFLOWS:
*Composition_Shingle_Roofing_Residential = Residential_Construction*CSR*

OUTFLOWS:
*Compostition_Shingle_Removal_Residential = Residential_Removal*CSR*

*Composition_Shingle_Roofing_Stock_Residential_Utility(t) = Composition_Shingle_Roofing_Stock_Residential_Utility(t - dt) + (Composition_Shigle_Roofing__Residential_Utility - Composition_Shingle_Removal_Residential_Utility) * dt*
INIT Composition_Shingle_Roofing_Stock_Residential_Utility = 0

INFLOWS:
*Composition_Shigle_Roofing__Residential_Utility = CSRU*Residential_Utility_Construction*

OUTFLOWS:
*Composition_Shingle_Removal_Residential_Utility = Residential_Utility_Removal*CSRU*

*Fixtures(t) = Fixtures(t - dt) + (Fixture_Removal_Residential - Reuse_Fixture_Residential - Fixture_Demolition - Extra_NH_Fixture_Reuse) * dt*
INIT Fixtures = 0

INFLOWS:
*Fixture_Removal_Residential = Residential_Removal*FxR*

OUTFLOWS:
Reuse_Fixture_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
*IF Extra_NH_Reuse_Rate = 0 AND (FxR*Residential_Construction) >*
*(Fixture_Removal_Residential)*Residential_Deconstruction__Fraction THEN*
*(Fixture_Removal_Residential*Residential_Deconstruction__Fraction) ELSE*
*(FxR*Residential_Construction)*

Fixture_Demolition = Residential_Demolition_Fraction(Fixture_Removal_Residential)*

Extra_NH_Fixture_Reuse =
(Residential_Deconstruction__Fraction(Fixture_Removal_Residential))-*
Reuse_Fixture_Residential

*Fixture_Stock__Residential(t) = Fixture_Stock__Residential(t - dt) + (Reuse_Fixture_Residential + Fixture_Residential - Fixture_Removal_Residential) * dt*
INIT Fixture_Stock__Residential = 0

INFLOWS:
Reuse_Fixture_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
*IF Extra_NH_Reuse_Rate = 0 AND (FxR*Residential_Construction) >*
*(Fixture_Removal_Residential)*Residential_Deconstruction__Fraction THEN*
*(Fixture_Removal_Residential*Residential_Deconstruction__Fraction) ELSE*
*(FxR*Residential_Construction)*

*Fixture_Residential = (Residential_Construction*FxR)-Reuse_Fixture_Residential*

OUTFLOWS:
*Fixture_Removal_Residential = Residential_Removal*FxR*

*Foundation(t) = Foundation(t - dt) + (Foundation_Removal_Residential + Foundation_Removal_Residential_Utility + Foundation_Removal_Commercial + Foundation__Removal_Industrial - Foundation_Demolition - Foundation_Recycling) * dt*
INIT Foundation = 0

INFLOWS:
*Foundation_Removal_Residential = (Residential_Removal*FdR)-*
*((Residential_Construction*FdR)*Foundation_Rehab_Fraction)*

*Foundation_Removal_Residential_Utility = (Residential_Utility_Removal*FdRU)-*
*((Residential_Utility_Construction*FdRU)*Foundation_Rehab_Fraction)*

*Foundation_Removal_Commercial = (Commercial_Removal*FdC)-((Commercial_Construction*FdC)*Foundation_Rehab_Fraction)*

*Foundation__Removal_Industrial = (Industrial_Removal*FdI)-((Industrial_Construction*FdI)*Foundation_Rehab_Fraction)*

OUTFLOWS:
*Foundation_Demolition = (Foundation_Removal_Commercial*Commercial_Demolition_Fraction)+(Foundation_Removal_Residential*Residential_Demolition_Fraction)+(Foundation_Removal_Residential_Utility*Residential_Utility_Demolition_Fraction)+(Foundation__Removal_Industrial*Industrial_Demolition_Fraction)*

*Foundation_Recycling = (Foundation_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Foundation_Removal_Residential*Residential_Deconstruction__Fraction)+(Foundation_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)+(Foundation__Removal_Industrial*Industrial_Deconstruction_Fraction)*

*Foundation_Stock_Commercial(t) = Foundation_Stock_Commercial(t - dt) + (Foundation_Commercial - Foundation_Removal_Commercial) * dt*
INIT Foundation_Stock_Commercial = 0

INFLOWS:
*Foundation_Commercial = (Commercial_Construction*FdC)-((Commercial_Construction*FdC)*Foundation_Rehab_Fraction)*

OUTFLOWS:
*Foundation_Removal_Commercial = (Commercial_Removal*FdC)-((Commercial_Construction*FdC)*Foundation_Rehab_Fraction)*

*Foundation_Stock_Industrial(t) = Foundation_Stock_Industrial(t - dt) + (Foundation_Industrial - Foundation__Removal_Industrial) * dt*
INIT Foundation_Stock_Industrial = 0

INFLOWS:
*Foundation_Industrial = (Industrial_Construction*FdI)-((Industrial_Construction*FdI)*Foundation_Rehab_Fraction)*

OUTFLOWS:
*Foundation__Removal_Industrial = (Industrial_Removal*FdI)-((Industrial_Construction*FdI)*Foundation_Rehab_Fraction)*

*Foundation_Stock_Residential(t) = Foundation_Stock_Residential(t - dt) + (Foundation_Residential - Foundation_Removal_Residential) * dt*
INIT Foundation_Stock_Residential = 0

INFLOWS:
*Foundation_Residential = (Residential_Construction*FdR)-((Residential_Construction*FdR)*Foundation_Rehab_Fraction)*

OUTFLOWS:
*Foundation_Removal_Residential = (Residential_Removal*FdR)-((Residential_Construction*FdR)*Foundation_Rehab_Fraction)*

*Foundation_Stock_Residential_Utility(t) = Foundation_Stock_Residential_Utility(t - dt) + (Foundation_Residential_Utility - Foundation_Removal_Residential_Utility) * dt*
INIT Foundation_Stock_Residential_Utility = 0

INFLOWS:
*Foundation_Residential_Utility = (Residential_Utility_Construction*FdRU)-((Residential_Utility_Construction*FdRU)*Foundation_Rehab_Fraction)*

OUTFLOWS:
*Foundation_Removal_Residential_Utility = (Residential_Utility_Removal*FdRU)-((Residential_Utility_Construction*FdRU)*Foundation_Rehab_Fraction)*

*Interior_Drywall_Covering(t) = Interior_Drywall_Covering(t - dt) + (Interior_Drywall_Removal_Residential + Interior_Drywall_Removal_Commercial - Interior_Drywall_Demolition) * dt*
INIT Interior_Drywall_Covering = 0

INFLOWS:
*Interior_Drywall_Removal_Residential = Residential_Removal*IDR*

*Interior_Drywall_Removal_Commercial = Commercial_Removal*IDC*

OUTFLOWS:
Interior_Drywall_Demolition = Interior_Drywall_Removal_Commercial+Interior_Drywall_Removal_Residential

*Interior_Drywall_Covering_Stock_Commercial(t) = Interior_Drywall_Covering_Stock_Commercial(t - dt) + (Interior_Drywall_Covering_Commercial - Interior_Drywall_Removal_Commercial) * dt*
INIT Interior_Drywall_Covering_Stock_Commercial = 0

INFLOWS:
*Interior_Drywall_Covering_Commercial = Commercial_Construction*IDC*

OUTFLOWS:
*Interior_Drywall_Removal_Commercial = Commercial_Removal*IDC*

*Interior_Drywall_Covering_Stock_Residential(t) = Interior_Drywall_Covering_Stock_Residential(t - dt) + (Interior_Drywall_Covering_Residential - Interior_Drywall_Removal_Residential) * dt*
INIT Interior_Drywall_Covering_Stock_Residential = 0

INFLOWS:
*Interior_Drywall_Covering_Residential = Residential_Construction*IDR*

OUTFLOWS:
*Interior_Drywall_Removal_Residential = Residential_Removal*IDR*

*Interior_Plaster_Covering(t) = Interior_Plaster_Covering(t - dt) + (Interior_Plaster_Removal_Residential - Interior_Plaster_Demolition) * dt*
INIT Interior_Plaster_Covering = 0

INFLOWS:
*Interior_Plaster_Removal_Residential = Residential_Removal*IPR*

OUTFLOWS:
Interior_Plaster_Demolition = Interior_Plaster_Removal_Residential

*Interior_Plaster_Covering_Stock_Residential(t) = Interior_Plaster_Covering_Stock_Residential(t - dt) + (Interior_Plaster_Covering_Residential - Interior_Plaster_Removal_Residential) * dt*
INIT Interior_Plaster_Covering_Stock_Residential = 0

INFLOWS:
*Interior_Plaster_Covering_Residential = Residential_Construction*IPR*

OUTFLOWS:
*Interior_Plaster_Removal_Residential = Residential_Removal*IPR*

*Masonry_Siding(t) = Masonry_Siding(t - dt) + (Masonry_Siding_Removal_Commercial + Masonry_Siding_Removal_Industrial - Reuse_Masonry_Siding_Commercial - Masonry_Siding_Demolition - Extra_NH_Masonry_Siding_Reuse - Masonry_Siding_Recycling) * dt*
INIT Masonry_Siding = 0

INFLOWS:
*Masonry_Siding_Removal_Commercial = Commercial_Removal*MC*

*Masonry_Siding_Removal_Industrial = Industrial_Removal*MI*

OUTFLOWS:
*Reuse_Masonry_Siding_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (MC*Commercial_Construction) > (Masonry_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction) THEN (Masonry_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction) ELSE (MC*Commercial_Construction)*

*Masonry_Siding_Demolition = (Masonry_Siding_Removal_Commercial*Commercial_Demolition_Fraction)+(Industrial_Demolition_Fraction*Masonry_Siding_Removal_Industrial)*

*Extra_NH_Masonry_Siding_Reuse = (Commercial_Deconstruction_Fraction*Masonry_Siding_Removal_Commercial)-Reuse_Masonry_Siding_Commercial*

*Masonry_Siding_Recycling = Industrial_Deconstruction_Fraction*Masonry_Siding_Removal_Industrial*

*Masonry_Siding_Stock_Commercial(t) = Masonry_Siding_Stock_Commercial(t - dt) + (Reuse_Masonry_Siding_Commercial + Masonry_Siding_Commercial - Masonry_Siding_Removal_Commercial) * dt*
INIT Masonry_Siding_Stock_Commercial = 0

INFLOWS:
*Reuse_Masonry_Siding_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (MC*Commercial_Construction) > (Masonry_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction) THEN (Masonry_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction) ELSE (MC*Commercial_Construction)*

*Masonry_Siding_Commercial = (MC*Commercial_Construction)- Reuse_Masonry_Siding_Commercial*

OUTFLOWS:
*Masonry_Siding_Removal_Commercial = Commercial_Removal*MC*

*Masonry_Siding_Stock_Industrial(t) = Masonry_Siding_Stock_Industrial(t - dt) + (Masonry_Siding_Industrial - Masonry_Siding_Removal_Industrial) * dt*
INIT Masonry_Siding_Stock_Industrial = 0

INFLOWS:
*Masonry_Siding_Industrial = (MI*Industrial_Construction)*

OUTFLOWS:
*Masonry_Siding_Removal_Industrial = Industrial_Removal*MI*

*Membrane_Roofing(t) = Membrane_Roofing(t - dt) + (Membrane_Roofing_Removal_Commercial + Membrane_Roofing_Removal_Industrial - Membrane_Roofing_Demolition) * dt*
INIT Membrane_Roofing = 0

INFLOWS:
*Membrane_Roofing_Removal_Commercial = Commercial_Removal*MRC*

*Membrane_Roofing_Removal_Industrial = Industrial_Removal*MRI*

OUTFLOWS:
Membrane_Roofing_Demolition = Membrane_Roofing_Removal_Commercial+Membrane_Roofing_Removal_Industrial

*Membrane_Roofing_Stock_Commercial(t) = Membrane_Roofing_Stock_Commercial(t - dt) + (Membrane_Roofing_Commercial - Membrane_Roofing_Removal_Commercial) * dt*
INIT Membrane_Roofing_Stock_Commercial = 0

INFLOWS:
*Membrane_Roofing_Commercial = Commercial_Construction*MRC*

OUTFLOWS:
*Membrane_Roofing_Removal_Commercial = Commercial_Removal*MRC*

*Membrane_Roofing_Stock_Industrial(t) = Membrane_Roofing_Stock_Industrial(t - dt) + (Membrane_Roofing__Industrial - Membrane_Roofing_Removal_Industrial) * dt*
INIT Membrane_Roofing_Stock_Industrial = 0

INFLOWS:
*Membrane_Roofing__Industrial = Industrial_Construction*MRI*

OUTFLOWS:
*Membrane_Roofing_Removal_Industrial = Industrial_Removal*MRI*

*Miscellaneous_Debris(t) = Miscellaneous_Debris(t - dt) + (Miscellaneous_Debris_Removal_Industrial + Miscellaneous_Debris_Removal_Residential + Miscellaneous_Debris_Removal_Residential_Utility + Miscellaneous_Debris_Removal_Commercial - Miscellaneous_Debris_Demolition) * dt*
INIT Miscellaneous_Debris = 0

INFLOWS:
*Miscellaneous_Debris_Removal_Industrial = MD*Industrial_Removal*

*Miscellaneous_Debris_Removal_Residential = MD*Residential_Removal*

*Miscellaneous_Debris_Removal_Residential_Utility = MD*Residential_Utility_Removal*

*Miscellaneous_Debris_Removal_Commercial = Commercial_Removal*MD*

OUTFLOWS:
Miscellaneous_Debris_Demolition = Miscellaneous_Debris_Removal_Commercial+Miscellaneous_Debris_Removal_Industrial+Miscellaneous_Debris_Removal_Residential+Miscellaneous_Debris_Removal_Residential_Utility

*Miscellaneous_Stock_Commercial(t) = Miscellaneous_Stock_Commercial(t - dt) + (Miscellaneous_Debris_Commercial - Miscellaneous_Debris_Removal_Commercial) * dt*
INIT Miscellaneous_Stock_Commercial = 0

INFLOWS:
*Miscellaneous_Debris_Commercial = Commercial_Construction*MD*

OUTFLOWS:
*Miscellaneous_Debris_Removal_Commercial = Commercial_Removal*MD*

*Miscellaneous_Stock_Industrial(t) = Miscellaneous_Stock_Industrial(t - dt) + (Midscellaneous_Debris_Industrial - Miscellaneous_Debris_Removal_Industrial) * dt*
INIT Miscellaneous_Stock_Industrial = 0

INFLOWS:
*Midscellaneous_Debris_Industrial = Industrial_Construction*MD*

OUTFLOWS:
*Miscellaneous_Debris_Removal_Industrial = MD*Industrial_Removal*

*Miscellaneous_Stock_Residential(t) = Miscellaneous_Stock_Residential(t - dt) + (Miscellaneous_Debris_Residential - Miscellaneous_Debris_Removal_Residential) * dt*
INIT Miscellaneous_Stock_Residential = 0

INFLOWS:
*Miscellaneous_Debris_Residential = Residential_Construction*MD*

OUTFLOWS:
*Miscellaneous_Debris_Removal_Residential = MD*Residential_Removal*

*Miscellaneous_Stock_Residential_Utility(t) = Miscellaneous_Stock_Residential_Utility(t - dt) + (Miscellaneous_Debris_Residential_Utility - Miscellaneous_Debris_Removal_Residential_Utility) * dt*
INIT Miscellaneous_Stock_Residential_Utility = 0

INFLOWS:
*Miscellaneous_Debris_Residential_Utility = MD*Residential_Utility_Construction*

OUTFLOWS:
*Miscellaneous_Debris_Removal_Residential_Utility = MD*Residential_Utility_Removal*

*Shake_Shingle_Roofing(t) = Shake_Shingle_Roofing(t - dt) + (Shake_Shingle_Removal_Residential - Shake_Shingle_Demolition - Shake_Shingle_Recycling) * dt*
INIT Shake_Shingle_Roofing = 0

INFLOWS:
*Shake_Shingle_Removal_Residential = Residential_Removal*SSR*

OUTFLOWS:
*Shake_Shingle_Demolition = Residential_Demolition_Fraction*Shake_Shingle_Removal_Residential*

*Shake_Shingle_Recycling = Residential_Deconstruction__Fraction*Shake_Shingle_Removal_Residential*

*Shake_Shingle_Roofing_Stock_Residential(t) = Shake_Shingle_Roofing_Stock_Residential(t - dt) + (Shake_Shingle_Roofing_Residential - Shake_Shingle_Removal_Residential) * dt*
INIT Shake_Shingle_Roofing_Stock_Residential = 0

INFLOWS:
*Shake_Shingle_Roofing_Residential = Residential_Construction*SSR*

OUTFLOWS:
*Shake_Shingle_Removal_Residential = Residential_Removal*SSR*

*Sheathing(t) = Sheathing(t - dt) + (Sheathing_Removal_Residential + Sheathing_Removal_Commercial + Sheathing_Removal_Residential_Utility - Sheathing_Demolition) * dt*
INIT Sheathing = 0

INFLOWS:
*Sheathing_Removal_Residential = Residential_Removal*ShR*

*Sheathing_Removal_Commercial = Commercial_Removal*ShC*

*Sheathing_Removal_Residential_Utility = Residential_Utility_Removal*ShRU*

OUTFLOWS:
Sheathing_Demolition =
Sheathing_Removal_Commercial+Sheathing_Removal_Residential+Sheathing_Removal_Residential_Utility

*Sheathing_Stock_Commercial(t) = Sheathing_Stock_Commercial(t - dt) + (Sheathing_Commercial - Sheathing_Removal_Commercial) * dt*
INIT Sheathing_Stock_Commercial = 0

INFLOWS:
*Sheathing_Commercial = Commercial_Construction*ShC*

OUTFLOWS:
*Sheathing_Removal_Commercial = Commercial_Removal*ShC*

*Sheathing_Stock_Residential_Utility(t) = Sheathing_Stock_Residential_Utility(t - dt) + (Sheathing_Residential_Utility - Sheathing_Removal_Residential_Utility) * dt*
INIT Sheathing_Stock_Residential_Utility = 0

INFLOWS:
*Sheathing_Residential_Utility = Residential_Utility_Construction*ShRU*

OUTFLOWS:
*Sheathing_Removal_Residential_Utility = Residential_Utility_Removal*ShRU*

*Sheating_Stock_Residential(t) = Sheating_Stock_Residential(t - dt) + (Sheathing_Residential - Sheathing_Removal_Residential) * dt*
INIT Sheating_Stock_Residential = 0

INFLOWS:
*Sheathing_Residential = Residential_Construction*ShR*

OUTFLOWS:
*Sheathing_Removal_Residential = Residential_Removal*ShR*

*Steel_Framing(t) = Steel_Framing(t - dt) + (Steel_Framing_Removal_Commercial + Steel_Framing_Removal_Industrial - Steel_Framing_Recycling) * dt*
INIT Steel_Framing = 0

INFLOWS:
*Steel_Framing_Removal_Commercial = Commercial_Removal*SFC*
*Steel_Framing_Removal_Industrial = Industrial_Removal*SFI*

OUTFLOWS:
Steel_Framing_Recycling =
Steel_Framing_Removal_Commercial+Steel_Framing_Removal_Industrial

Steel_Framing_Stock_Commercial(t) = Steel_Framing_Stock_Commercial(t - dt) +
*(Steel_Framing_Commercial - Steel_Framing_Removal_Commercial) * dt*
INIT Steel_Framing_Stock_Commercial = 0

INFLOWS:
*Steel_Framing_Commercial = Commercial_Construction*SFC*

OUTFLOWS:
*Steel_Framing_Removal_Commercial = Commercial_Removal*SFC*

Steel_Framing_Stock_Industrial(t) = Steel_Framing_Stock_Industrial(t - dt) +
*(Steel_Framing_Industrial - Steel_Framing_Removal_Industrial) * dt*
INIT Steel_Framing_Stock_Industrial = 0

INFLOWS:
*Steel_Framing_Industrial = Industrial_Construction*SFI*

OUTFLOWS:
*Steel_Framing_Removal_Industrial = Industrial_Removal*SFI*

Structural_Masonry(t) = Structural_Masonry(t - dt) +
(Structural_Masonry_Removal_Commercial + Structural_Masonry_Removal_Residential +
Structural_Masonry_Removal_Industrial - Reuse_Structural_Masonry_Residential -
Structural_Masonry_Demolition - Extra_NH_Structural_Masonry_Reuse -
*Structural_Masonry_Recycling) * dt*
INIT Structural_Masonry = 0

INFLOWS:
*Structural_Masonry_Removal_Commercial = Commercial_Removal*SC*

*Structural_Masonry_Removal_Residential = Residential_Removal*SMR*

*Structural_Masonry_Removal_Industrial = Industrial_Removal*SI*

OUTFLOWS:
Reuse_Structural_Masonry_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
*IF Extra_NH_Reuse_Rate = 0 AND (SMR*Residential_Construction) >*
*(Structural_Masonry_Removal_Residential*Residential_Deconstruction__Fraction) THEN*
*(Structural_Masonry_Removal_Residential*Residential_Deconstruction__Fraction) ELSE*
*(SMR*Residential_Construction)*
Structural_Masonry_Demolition =
*(Structural_Masonry_Removal_Commercial*Commercial_Demolition_Fraction)+(Structural_M*
*asonry_Removal_Industrial*Industrial_Demolition_Fraction)+(Structural_Masonry_Removal_R*
*esidential*Residential_Demolition_Fraction)*
Extra_NH_Structural_Masonry_Reuse =
*(Structural_Masonry_Removal_Residential*Residential_Deconstruction__Fraction)-*
Reuse_Structural_Masonry_Residential

*Structural_Masonry_Recycling =
(Structural_Masonry_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Structural_Masonry_Removal_Industrial*Industrial_Deconstruction_Fraction)
Structural_Masonry_Stock_Commercial(t) = Structural_Masonry_Stock_Commercial(t - dt) + (Structural_Masonry_Commercial - Structural_Masonry_Removal_Commercial) * dt
INIT Structural_Masonry_Stock_Commercial = 0*

*INFLOWS:
Structural_Masonry_Commercial = (Commercial_Construction*SC)*

*OUTFLOWS:
Structural_Masonry_Removal_Commercial = Commercial_Removal*SC*

*Structural_Masonry_Stock_Industrial(t) = Structural_Masonry_Stock_Industrial(t - dt) + (Structural_Masonry_Industrial - Structural_Masonry_Removal_Industrial) * dt
INIT Structural_Masonry_Stock_Industrial = 0*

*INFLOWS:
Structural_Masonry_Industrial = (Industrial_Construction*SI)*

*OUTFLOWS:
Structural_Masonry_Removal_Industrial = Industrial_Removal*SI*

*Structural_Masonry_Stock_Residential(t) = Structural_Masonry_Stock_Residential(t - dt) + (Reuse_Structural_Masonry_Residential + Structural_Masonry_Residential - Structural_Masonry_Removal_Residential) * dt
INIT Structural_Masonry_Stock_Residential = 0*

*INFLOWS:
Reuse_Structural_Masonry_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
IF Extra_NH_Reuse_Rate = 0 AND (SMR*Residential_Construction) >
(Structural_Masonry_Removal_Residential*Residential_Deconstruction__Fraction) THEN
(Structural_Masonry_Removal_Residential*Residential_Deconstruction__Fraction) ELSE
(SMR*Residential_Construction)*

*Structural_Masonry_Residential = (Residential_Construction*SMR)-
Reuse_Structural_Masonry_Residential*

*OUTFLOWS:
Structural_Masonry_Removal_Residential = Residential_Removal*SMR*

*Vinyl_Siding(t) = Vinyl_Siding(t - dt) + (Vinyl_Siding_Removal_Commercial + Vinyl_Siding_Removal_Residential + Vinyl_Siding_Removal_Residential_Utility - Reuse_Vinyl_Siding_Residential_Utility - Reuse_Vinyl_Siding_Residential - Reuse_Vinyl_Siiding_Commercial - Vinyl_Siding_Demolition - Extra_NH_Vinyl_Siding_Reuse) * dt
INIT Vinyl_Siding = 0*

*INFLOWS:
Vinyl_Siding_Removal_Commercial = Commercial_Removal*VC*

*Vinyl_Siding_Removal_Residential = Residential_Removal*VR*

*Vinyl_Siding_Removal_Residential_Utility = Residential_Utility_Removal*VRU*

OUTFLOWS:
*Reuse_Vinyl_Siding_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (VRU*Residential_Utility_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Utility_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Utility_Fraction_Vinyl_Siding*(VRU*Residential_Utility_Construction)*

*Reuse_Vinyl_Siding_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (VR*Residential_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction) +(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Fraction_Vinyl_Siding*(VR*Residential_Construction)*

*Reuse_Vinyl_Siding_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (VC*Commercial_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Commercial_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Commercial_Fraction_Vinyl_Siding*(VC*Commercial_Construction)*

*Vinyl_Siding_Demolition = (Vinyl_Siding_Removal_Commercial*Commercial_Demolition_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Demolition_Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Demolition_Fraction)*

*Extra_NH_Vinyl_Siding_Reuse = ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction))-Reuse_Vinyl_Siding_Residential-Reuse_Vinyl_Siding_Residential_Utility-Reuse_Vinyl_Siiding_Commercial*

*Vinyl_Siding_Stock_Commercial(t) = Vinyl_Siding_Stock_Commercial(t - dt) + (Reuse_Vinyl_Siiding_Commercial + Vinyl_Siding_Commercial - Vinyl_Siding_Removal_Commercial) * dt*
INIT Vinyl_Siding_Stock_Commercial = 0

INFLOWS:
Reuse_Vinyl_Siiding_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE

*IF Extra_NH_Reuse_Rate = 0 AND (VC*Commercial_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Commercial_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Commercial_Fraction_Vinyl_Siding*(VC*Commercial_Construction)*

*Vinyl_Siding_Commercial = (VC*Commercial_Construction)-Reuse_Vinyl_Siiding_Commercial*

OUTFLOWS:
*Vinyl_Siding_Removal_Commercial = Commercial_Removal*VC*

*Vinyl_Siding_Stock_Residential(t) = Vinyl_Siding__Stock_Residential(t - dt) + (Reuse_Vinyl_Siding_Residential + Vinyl_Siding_Residential - Vinyl_Siding_Removal_Residential) * dt*
INIT Vinyl_Siding__Stock_Residential = 0

INFLOWS:
Reuse_Vinyl_Siding_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
*IF Extra_NH_Reuse_Rate = 0 AND (VR*Residential_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Fraction_Vinyl_Siding*(VR*Residential_Construction)*

*Vinyl_Siding_Residential = (VR*Residential_Construction)-Reuse_Vinyl_Siding_Residential*

OUTFLOWS:
*Vinyl_Siding_Removal_Residential = Residential_Removal*VR*

*Vinyl_Siding__Stock_Residential_Utility(t) = Vinyl_Siding__Stock_Residential_Utility(t - dt) + (Reuse_Vinyl_Siding_Residential_Utility + Vinyl_Siding_Residential_Utility - Vinyl_Siding_Removal_Residential_Utility) * dt*
INIT Vinyl_Siding__Stock_Residential_Utility = 0

INFLOWS:
Reuse_Vinyl_Siding_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
*IF Extra_NH_Reuse_Rate = 0 AND (VRU*Residential_Utility_Construction) > ((Vinyl_Siding_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Utility_Fraction_Vinyl_Siding*((Vinyl_Siding_Removal_Commercial*Commercial_*

*Deconstruction_Fraction)+(Vinyl_Siding_Removal_Residential*Residential_Deconstruction__Fraction)+(Vinyl_Siding_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Utility_Fraction_Vinyl_Siding*(VRU*Residential_Utility_Construction)*

*Vinyl_Siding_Residential_Utility = (VRU*Residential_Utility_Construction)-Reuse_Vinyl_Siding_Residential_Utility*

OUTFLOWS:
*Vinyl_Siding_Removal_Residential_Utility = Residential_Utility_Removal*VRU*

*Wood_Flooring(t) = Wood_Flooring(t - dt) + (Wood_Flooring_Removal_Residential - Reuse_Wood_Flooring_Residential - Flooring_Demolition - Extra_NH_Flooring_Reuse) * dt*
INIT Wood_Flooring = 0

INFLOWS:
*Wood_Flooring_Removal_Residential = WFR*Residential_Removal*

OUTFLOWS:
*Reuse_Wood_Flooring_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (WFR*Residential_Construction) > (Wood_Flooring_Removal_Residential)*Residential_Deconstruction__Fraction THEN (Wood_Flooring_Removal_Residential*Residential_Deconstruction__Fraction) ELSE (WFR*Residential_Construction)*

Flooring_Demolition = Residential_Demolition_Fraction(Wood_Flooring_Removal_Residential)*

Extra_NH_Flooring_Reuse = (Residential_Deconstruction__Fraction(Wood_Flooring_Removal_Residential))-Reuse_Wood_Flooring_Residential*

*Wood_Flooring_Stock_Residential(t) = Wood_Flooring_Stock_Residential(t - dt) + (Reuse_Wood_Flooring_Residential + Wood_Flooring_Residential - Wood_Flooring_Removal_Residential) * dt*
INIT Wood_Flooring_Stock_Residential = 0

INFLOWS:
*Reuse_Wood_Flooring_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (WFR*Residential_Construction) > (Wood_Flooring_Removal_Residential)*Residential_Deconstruction__Fraction THEN (Wood_Flooring_Removal_Residential*Residential_Deconstruction__Fraction) ELSE (WFR*Residential_Construction)*

*Wood_Flooring_Residential = (Residential_Construction*WFR)-Reuse_Wood_Flooring_Residential*

OUTFLOWS:
*Wood_Flooring_Removal_Residential = WFR*Residential_Removal*

Wood_Framing(t) = Wood_Framing(t - dt) + (Wood_Framing_Removal_Commercial +
Wood_Framing_Removal_Residential + Wood_Framing_Removal_Residential_Utility -
Reuse_Wood_Framing_Residential - Reuse_Wood_Framing_Residential_Utility -
Reuse_Wood_Framing_Commercial - Framing_Demolition - Extra_NH__Framing_Reuse) * dt
INIT Wood_Framing = 0

INFLOWS:
Wood_Framing_Removal_Commercial = Commercial_Removal*FC

Wood_Framing_Removal_Residential = Residential_Removal*FR

Wood_Framing_Removal_Residential_Utility = Residential_Utility_Removal*FRU

OUTFLOWS:
Reuse_Wood_Framing_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
IF Extra_NH_Reuse_Rate = 0 AND (FR*Residential_Construction) >
((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Frami
ng_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_R
esidential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN
Residential_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commercial_D
econstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__
Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_F
raction)) ELSE Residential_Fraction_Wood_Framing*(FR*Residential_Construction)

Reuse_Wood_Framing_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
IF Extra_NH_Reuse_Rate = 0 AND (FRU*Residential_Utility_Construction) >
((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Frami
ng_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_R
esidential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN
Residential_Utility_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commer
cial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruct
ion__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstructi
on_Fraction)) ELSE
Residential_Utility_Fraction_Wood_Framing*(FRU*Residential_Utility_Construction)

Reuse_Wood_Framing_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE
IF Extra_NH_Reuse_Rate = 0 AND (FC*Commercial_Construction) >
((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Frami
ng_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_R
esidential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN
Commercial_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commercial_
Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction_
_Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_
Fraction)) ELSE Commercial_Fraction_Wood_Framing*(FC*Commercial_Construction)

Framing_Demolition =
(Wood_Framing_Removal_Commercial*Commercial_Demolition_Fraction)+(Wood_Framing_
Removal_Residential*Residential_Demolition_Fraction)+(Wood_Framing_Removal_Residential
_Utility*Residential_Utility_Demolition_Fraction)

*Extra_NH__Framing_Reuse = ((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction))-Reuse_Wood_Framing_Commercial-Reuse_Wood_Framing_Residential-Reuse_Wood_Framing_Residential_Utility*

*Wood_Framing_Stock_Commercial(t) = Wood_Framing_Stock_Commercial(t - dt) + (Reuse_Wood_Framing_Commercial + Wood_Framing_Commercial - Wood_Framing_Removal_Commercial) * dt*
INIT Wood_Framing_Stock_Commercial = 0

INFLOWS:
*Reuse_Wood_Framing_Commercial = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (FC*Commercial_Construction) > ((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Commercial_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Commercial_Fraction_Wood_Framing*(FC*Commercial_Construction)*

*Wood_Framing_Commercial = (FC*Commercial_Construction)-Reuse_Wood_Framing_Commercial*

OUTFLOWS:
*Wood_Framing_Removal_Commercial = Commercial_Removal*FC*

*Wood_Framing_Stock_Residential_Utility(t) = Wood_Framing_Stock_Residential_Utility(t - dt) + (Reuse_Wood_Framing_Residential_Utility + Wood_Framing__Residential_Utility - Wood_Framing_Removal_Residential_Utility) * dt*
INIT Wood_Framing_Stock_Residential_Utility = 0

INFLOWS:
*Reuse_Wood_Framing_Residential_Utility = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (FRU*Residential_Utility_Construction) > ((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Utility_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Utility_Fraction_Wood_Framing*(FRU*Residential_Utility_Construction)*

*Wood_Framing__Residential_Utility = (Residential_Utility_Construction*FRU)-Reuse_Wood_Framing_Residential_Utility*

OUTFLOWS:
*Wood_Framing_Removal_Residential_Utility = Residential_Utility_Removal*FRU*

*Wood__Framing_Stock_Residential(t) = Wood__Framing_Stock_Residential(t - dt) + (Reuse_Wood_Framing_Residential + Wood_Framing_Residential - Wood_Framing_Removal_Residential) * dt*
INIT Wood__Framing_Stock_Residential = 0

INFLOWS:
*Reuse_Wood_Framing_Residential = IF Extra_NH_Reuse_Rate = 1 THEN 0 ELSE IF Extra_NH_Reuse_Rate = 0 AND (FR*Residential_Construction) > ((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) THEN Residential_Fraction_Wood_Framing*((Wood_Framing_Removal_Commercial*Commercial_Deconstruction_Fraction)+(Wood_Framing_Removal_Residential*Residential_Deconstruction__Fraction)+(Wood_Framing_Removal_Residential_Utility*Residential_Utility_Deconstruction_Fraction)) ELSE Residential_Fraction_Wood_Framing*(FR*Residential_Construction)*

*Wood_Framing_Residential = (Residential_Construction*FR)-Reuse_Wood_Framing_Residential*

OUTFLOWS:
*Wood_Framing_Removal_Residential = Residential_Removal*FR*

*Commercial_Construction = (Residential_Construction*Commercial_Ratio)+((Residential_Construction*Commercial_Ratio)*Rehab_Ratio)*

Main Model Converters:

Commercial_Deconstruction_Fraction = 1-Commercial_Demolition_Fraction

Commercial_Demolition_Fraction = 1

*Commercial_Fraction_Vinyl_Siding = (Commercial_Construction*VC)/((Commercial_Construction*VC)+(Residential_Construction*VR)+(Residential_Utility_Construction*VRU))*

*Commercial_Fraction_Wood_Framing = (Commercial_Construction*FC)/((Commercial_Construction*FC)+(Residential_Construction*FR)+(Residential_Utility_Construction*FRU))*

Commercial_Ratio = 1

Commercial_Removal = (Commercial__Removal_Ratio(Commercial_Construction-(Commercial_Construction*Rehab_Fraction)))+(Commercial_Construction*Rehab_Fraction)*

Commercial__Removal_Ratio = 2.8

Construction_Rate = 0

CR = 0.0003

CRU = 0.0005

CSC = 0.0004

CSR = 0.0008

CSRU = 0.0025

FC = 0.0016

FdC = 0.0269

FdI = 0.0165

FdR = 0.0265

FdRU = 0.0152

Foundation_Rehab_Fraction = IF Economic_Summary.Rehab_Foundation? = 0 THEN 0 ELSE (Rehab_Ratio/(Rehab_Ratio+1))

FR = 0.0031

FRU = 0.0031

FxR = 0.0003

IDC = 0.0024

IDR = 0.002

*Industrial_Construction = (Residential_Construction*Industrial_Ratio)+((Residential_Construction*Industrial_Ratio)*Rehab_Ratio)*

Industrial_Deconstruction_Fraction = 1-Industrial_Demolition_Fraction

Industrial_Demolition_Fraction = 1

Industrial_Ratio = 1.48

Industrial_Removal = (Industrial__Removal_Ratio(Industrial_Construction-(Industrial_Construction*Rehab_Fraction)))+(Industrial_Construction*Rehab_Fraction)*

Industrial__Removal_Ratio = 0.75

IPR = 0.0036

MC = 0.0011

MD = 0.006

MI = 0.0010

MRC = 0.0006

MRI = 0.0027

Rehab_Fraction = Rehab_Ratio/(Rehab_Ratio+1)

Rehab_Ratio = 0.52

*Residential_Construction = IF Construction_Rate = 1 THEN Residential_Construction_Rate_High+(Rehab_Ratio*Residential_Construction_Rate_High) ELSE Residential_Construction_Rate_Low+(Rehab_Ratio*Residential_Construction_Rate_Low)*

Residential_Construction_Rate_High = 96556(1+0.03)^TIME*

Residential_Construction_Rate_Low = 96556(1-0.03)^TIME*

Residential_Deconstruction__Fraction = 1-Residential_Demolition_Fraction

Residential_Demolition_Fraction = 1

*Residential_Fraction_Clapboard_Siding = (Residential_Construction*CR)/((Residential_Construction*CR)+(Residential_Utility_Construction*CRU))*

*Residential_Fraction_Vinyl_Siding = (Residential_Construction*VR)/((Residential_Construction*VR)+(Commercial_Construction*VC)+(Residential_Utility_Construction*VRU))*

*Residential_Fraction_Wood_Framing = (Residential_Construction*FR)/((Residential_Construction*FR)+(Commercial_Construction*FC)+(Residential_Utility_Construction*FRU))*

Residential_Removal = (Residential_Removal_Ratio(Residential_Construction-(Residential_Construction*Rehab_Fraction)))+(Residential_Construction*Rehab_Fraction)*

Residential_Removal_Ratio = 0.47

*Residential_Utility_Construction = (Residential_Construction*Residential_Utility_Ratio)+((Residential_Construction*Residential_Utility_Ratio)*Rehab_Ratio)*

Residential_Utility_Deconstruction_Fraction = 1-Residential_Utility_Demolition_Fraction

Residential_Utility_Demolition_Fraction = 1

*Residential_Utility_Fraction_Clapboard_Siding = (Residential_Utility_Construction*CRU)/((Residential_Utility_Construction*CRU)+(Residential_Construction*CR))*

*Residential_Utility_Fraction_Vinyl_Siding = (Residential_Utility_Construction*VRU)/((VRU*Residential_Utility_Construction)+(Commercial_Construction*VC)+(Residential_Construction*VR))*

*Residential_Utility_Fraction_Wood_Framing = (Residential_Utility_Construction*FRU)/((Residential_Utility_Construction*FRU)+(Residential_Construction*FR)+(Commercial_Construction*FC))*

Residential_Utility_Ratio = 0.03

Residential_Utility_Removal = (Residential_Utility_Removal_Ratio(Residential_Utility_Construction-(Residential_Utility_Construction*Rehab_Fraction)))+(Residential_Utility_Construction*Rehab_Fraction)*

Residential_Utility_Removal_Ratio = 2

SC = 0.011

SFC = 0.001

SFI = 0.0021

ShC = 0.0002

ShR = 0.0008

ShRU = 0.0015

SI = 0.01

SMR = .0004

SSR = 0.001

VC = 0.0001

VR = 0.0001

VRU = 0.0002

WFR = 0.0015

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Economic Summary Sub-Model Converters:

annual_hours_worked = 1768

CD = 19.89

Commercial_Deconstruction = .Commercial_Removal.Commercial_Deconstruction_Fraction*
Commercial_Deconstruction_Cost = CD-Commercial_Foundation_Decon_Cost

Commercial_Demolition = .Commercial_Removal.Commercial_Demolition_Fraction*

Commercial_Demolition_Cost = 14.57

Commercial_Foundation = 3.53

*Commercial_Foundation_Decon_Cost = IF Rehab_Foundation? = 0 THEN 0 ELSE (Rehab_Fraction*Commercial_Foundation)*

Crew_Chiefs = 0.0008

hours_per_square_foot = .37

ID = 16.4

Industrial_Deconstruction = .Industrial_Deconstruction_Fraction.Industrial_Removal*

Industrial_Deconstruction_Cost = ID-Industrial_Foundation_Decon_Cost

Industrial_Demolition = .Industrial_Demolition_Fraction.Industrial_Removal*

Industrial_Demolition_Cost = 10.88

Industrial_Foundation = 2.17

*Industrial_Foundation_Decon_Cost = IF Rehab_Foundation? = 0 THEN 0 ELSE (Rehab_Fraction*Industrial_Foundation)*

Laborers_1 = 0.0016

Laborers_2 = 0.0016

laborers_per_hr = .075

RD = 18.09

Rehab_Foundation? = 1

Rehab_Fraction = .Rehab_Ratio/(.Rehab_Ratio+1)

Residential_Deconstruction = .Residential_Deconstruction__Fraction.Residential_Removal*

Residential_Deconstruction_Cost = RD-Residential_Foundation_Decon_Cost

Residential_Demolition = .Residential_Demolition_Fraction.Residential_Removal*

Residential_Demolition_Cost = 13.18

Residential_Foundation = 3.47

*Residential_Foundation_Decon_Cost = IF Rehab_Foundation? = 0 THEN 0 ELSE (Rehab_Fraction*Residential_Foundation)*

Residential_Utility_Deconstruction = .Residential_Utility_Deconstruction_Fraction.Residential_Utility_Removal*

Residential_Utility_Deconstruction_Cost = RUD-Residential_Utility_Foundation_Decon_Cost

Residential_Utility_Demolition = .Residential_Utility_Demolition_Fraction.Residential_Utility_Removal*

Residential_Utility_Foundation = 2.00

*Residential_Utility_Foundation_Decon_Cost = IF Rehab_Foundation? = 0 THEN 0 ELSE (Rehab_Fraction*Residential_Utility_Foundation)*

Residential_Utility__Demolition_Cost = 8.27

RUD = 14.15

Supervisors = 0.0003

Total_Commercial_Cost = Total_Commercial__Deconstruction_Cost + Total_Commercial__Demolition_Cost

*Total_Commercial__Deconstruction_Cost = Commercial_Deconstruction_Cost*Commercial_Deconstruction*

*Total_Commercial__Demolition_Cost = Commercial_Demolition_Cost*Commercial_Demolition*

Total_Cost = Total_Deconstruction_Cost + Total_Demolition_Cost

Total_Deconstruction = Commercial_Deconstruction + Industrial_Deconstruction + Residential_Deconstruction + Residential_Utility_Deconstruction

Total_Deconstruction_Cost = Total_Residential__Deconstruction_Cost + Total_Residential_Utility_Deconstruction_Cost + Total_Industrial__Deconstruction_Cost + Total_Commercial__Deconstruction_Cost

Total_Demolition_Cost = Total_Commercial_Cost + Total_Industrial__Demolition_Cost + Total_Residential_Utility__Demolition_Cost + Total_Residential__Demolition_Cost

Total_Industrial_Cost = Total_Industrial__Deconstruction_Cost + Total_Industrial__Demolition_Cost

*Total_Industrial__Deconstruction_Cost = Industrial_Deconstruction*Industrial_Deconstruction_Cost*

*Total_Industrial__Demolition_Cost = Industrial_Demolition*Industrial_Demolition_Cost*

*Total_Jobs = (Total_Deconstruction*hours_per_square_foot)/annual_hours_worked*

Total_Project_Jobs = Total_Deconstruction(Crew_Chiefs+Laborers_1+Laborers_2+Supervisors)*

Total_Residential_Cost = Total_Residential__Deconstruction_Cost + Total_Residential__Demolition_Cost

Total_Residential_Utility_Cost = Total_Residential_Utility__Demolition_Cost + Total_Residential_Utility_Deconstruction_Cost

*Total_Residential_Utility_Deconstruction_Cost = Residential_Utility_Deconstruction*Residential_Utility_Deconstruction_Cost*

*Total_Residential_Utility__Demolition_Cost = Residential_Utility_Demolition*Residential_Utility__Demolition_Cost*

*Total_Residential__Deconstruction_Cost = Residential_Deconstruction*Residential_Deconstruction_Cost*

*Total_Residential__Demolition_Cost = Residential_Demolition*Residential_Demolition_Cost*

Materials and Environmental Summary Sub-Model Converters:

*Demolition = Total_Demolition*TIME*

*Diversion = Total_Diversion*TIME*

*ECD = .Composition_Shingle_Demolition*WCD*

*ECR = .Composition_Shingle_Recycling*WCR*

*ECSD = .Clapboard_Siding_Demolition*WCSD*

*ECSRE = .Extra_NH_Clapboard_Siding_Reuse*WCSRE*

*ECSRR = .Reuse_Clapboard_Siiding_Residential*WCSRR*

*ECSRRU = .Reuse_Clapboard_Siding_Residential_Utility*WCSRRU*

*EFD = .Fixture_Demolition*WFD*

*EFdD = .Foundation_Demolition*WFdD*

*EFdR = .Foundation_Recycling*WFdR*

*EFlD = .Flooring_Demolition*WFlD*

*EFlE = .Extra_NH_Flooring_Reuse*WFlE*

*EFlR = .Reuse_Wood_Flooring_Residential*WFlR*

*EFRE = .Extra_NH_Fixture_Reuse*WFRE*

*EFRR = .Reuse_Fixture_Residential*WFRR*

*EIDD = .Interior_Drywall_Demolition*WIDD*

*EIPD = .Interior_Plaster_Demolition*WIPD*

*EMDD = .Miscellaneous_Debris_Demolition*WMDD*

*EMRD = .Membrane_Roofing_Demolition*WMRD*

*EMSD = .Masonry_Siding_Demolition*WMSD*

*EMSR = .Masonry_Siding_Recycling*WMSR*

*EMSRC = .Reuse_Masonry_Siding_Commercial*WMSRC*

*EMSRE = .Extra_NH_Masonry_Siding_Reuse*WMSRE*

*EShD = .Sheathing_Demolition*WShD*

*ESMD = .Structural_Masonry_Demolition*WSMD*

*ESMR = .Structural_Masonry_Recycling*WSMR*

*ESMRE = .Extra_NH_Structural_Masonry_Reuse*WSMRE*

*ESMRR = .Reuse_Structural_Masonry_Residential*WSMRR*

*ESR = .Steel_Framing_Recycling*WSR*

*ESSD = .Shake_Shingle_Demolition*WSSD*

*ESSR = .Shake_Shingle_Recycling*WSSR*

*EVSD = .Vinyl_Siding_Demolition*WVSD*

*EVSRC = .Reuse_Vinyl_Siiding_Commercial*WVSRC*

*EVSRE = .Extra_NH_Vinyl_Siding_Reuse*WVSRE*

*EVSRR = .Reuse_Vinyl_Siding_Residential*WVSRR*

*EVSRRU = .Reuse_Vinyl_Siding_Residential_Utility*WVSRRU*

*EWFD = .Framing_Demolition*WWFD*

*EWFRC = .Reuse_Wood_Framing_Commercial*WWFRC*

*EWFRE = .Extra_NH__Framing_Reuse*WWFRE*

*EWFRR = .Reuse_Wood_Framing_Residential*WWFRR*

*EWFRRU = .Reuse_Wood_Framing_Residential_Utility*WWFRRU*

*Extra_NH_Reuse = Total_Extra_NH_Reuse*TIME*

*Material = Total_Material*TIME*

*MTCE = Total_MTCE*TIME*

NH_Reuse = Reuse-Extra_NH_Reuse

*Recycling = Total_Recycling*TIME*

*Reuse = Total_Reuse*TIME*

Total_Commercial_Reuse = .Reuse_Masonry_Siding_Commercial + .Reuse_Vinyl_Siiding_Commercial + .Reuse_Wood_Framing_Commercial

Total_Demolition = .Clapboard_Siding_Demolition + .Composition_Shingle_Demolition + .Fixture_Demolition + .Foundation_Demolition + .Interior_Drywall_Demolition + .Interior_Plaster_Demolition + .Masonry_Siding_Demolition + .Membrane_Roofing_Demolition + .Miscellaneous_Debris_Demolition + .Framing_Demolition + .Shake_Shingle_Demolition + .Structural_Masonry_Demolition + .Vinyl_Siding_Demolition + .Flooring_Demolition + .Sheathing_Demolition

Total_Diversion = Total_Reuse + Total_Recycling

Total_Extra_NH_Reuse = .Extra_NH_Clapboard_Siding_Reuse + .Extra_NH_Fixture_Reuse + .Extra_NH_Masonry_Siding_Reuse + .Extra_NH_Structural_Masonry_Reuse + .Extra_NH_Vinyl_Siding_Reuse + .Extra_NH__Framing_Reuse + .Extra_NH_Flooring_Reuse

Total_Industrial_Reuse = 0

Total_Landfill__MTCE = ECD + ECSD + EFD + EFdD + EIDD + EIPD + EMDD + EMRD + EMSD + ESMD + ESSD + EVSD + EWFD + EFlD + EShD

Total_Material = Total_Diversion + Total_Demolition

Total_MTCE = Total_Reuse_and_Recyling_MTCE + Total_Landfill__MTCE

Total_Recycling = .Composition_Shingle_Recycling + .Shake_Shingle_Recycling + .Structural_Masonry_Recycling + .Masonry_Siding_Recycling + .Foundation_Recycling + .Steel_Framing_Recycling

Total_Residential_Reuse = .Reuse_Clapboard_Siiding_Residential + .Reuse_Fixture_Residential + .Reuse_Structural_Masonry_Residential + .Reuse_Vinyl_Siding_Residential + .Reuse_Wood_Framing_Residential + .Reuse_Wood_Flooring_Residential

Total_Residential_Utility_Reuse = .Reuse_Clapboard_Siding_Residential_Utility + .Reuse_Vinyl_Siding_Residential_Utility + .Reuse_Wood_Framing_Residential_Utility
Total_Reuse = Total_Commercial_Reuse + Total_Industrial_Reuse + Total_Residential_Reuse + Total_Residential_Utility_Reuse + Total_Extra_NH_Reuse

Total_Reuse_and_Recyling_MTCE = ECR + ECSRE + ECSRR + ECSRRU + EFdR + EFRE + EFRR + EMSR + EMSRC + EMSRE + ESMR + ESMRE + ESSR + EVSRC + EVSRE + EVSRR + EVSRRU + EWFRC + EWFRE + EWFRR + EWFRRU + EFlR + EFlE + ESR

WCD = 0.03

WCR = -0.003

WCSD = -0.115

WCSRE = -0.551

WCSRR = -0.551

WCSRRU = -0.551

WFD = -0.006

WFdD = 0.03

WFdR = -0.003

WFlD = -0.115

WFlE = -0.551

WFlR = -0.551

WFRE = -0.442

WFRR = -0.442

WIDD = 0.03

WIPD = 0.03

WMDD = 0.43

WMRD = 0.03

WMSD = 0.030

WMSR = -0.003

WMSRC = -0.078

WMSRE = -0.078

WShD = -0.115

WSMD = 0.03

WSMR = -0.003

WSMRE = -0.078

WSMRR = -0.078

WSR = -0.491

WSSD = -0.115

WSSR = -0.67

WVSD = 0.03

WVSRC = -0.417

WVSRE = -0.417

WVSRR = -0.417

WVSRRU = -0.417

WWFD = -0.115

WWFRC = -0.551

WWFRE = -0.551

WWFRR = -0.551

WWFRRU = -0.551

Scenario 2

Alternate Main Model Stocks and Flows:

Commercial_Deconstruction_Fraction = IF TIME < 3 THEN 0 ELSE (0.01(1+0.05)^TIME)*

Industrial_Deconstruction_Fraction = IF TIME < 3 THEN 0 ELSE (0.01(1+0.05)^TIME)*

Residential_Deconstruction__Fraction = IF TIME < 3 THEN 0 ELSE (0.05(1+0.1)^TIME)*

Residential_Utility_Deconstruction_Fraction = IF TIME < 3 THEN 0 ELSE (0.05(1+0.1)^TIME)*

*Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)*

Scenario 3

Alternate Main Model Stocks and Flows:

*Commercial_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 0.00), (2.00, 0.07), (3.00, 0.05), (4.00, 0.07), (5.00, 0.07), (6.00, 0.07), (7.00, 0.07), (8.00, 0.07), (9.00, 0.07), (10.0, 0.07), (11.0, 0.07), (12.0, 0.07), (13.0, 0.07), (14.0, 0.07), (15.0, 0.07), (16.0, 0.07), (17.0, 0.07), (18.0, 0.07), (19.0, 0.07), (20.0, 0.07), (21.0, 0.07), (22.0, 0.07), (23.0, 0.07), (24.0, 0.07), (25.0, 0.07)*

*Residential_Deconstruction__Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 0.44), (2.00, 0.44), (3.00, 0.44), (4.00, 0.44), (5.00, 0.44), (6.00, 0.44), (7.00, 0.44), (8.00, 0.44), (9.00, 0.44), (10.0, 0.44), (11.0, 0.44), (12.0, 0.44), (13.0, 0.44), (14.0, 0.44), (15.0, 0.44), (16.0, 0.44), (17.0, 0.44), (18.0, 0.44), (19.0, 0.44), (20.0, 0.44), (21.0, 0.44), (22.0, 0.44), (23.0, 0.44), (24.0, 0.44), (25.0, 0.44)*

*Residential_Utility_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 0.17), (2.00, 0.17), (3.00, 0.17), (4.00, 0.17), (5.00, 0.17), (6.00, 0.17), (7.00, 0.17), (8.00, 0.17), (9.00, 0.17), (10.0, 0.17), (11.0, 0.17), (12.0, 0.17), (13.0, 0.17), (14.0, 0.17), (15.0, 0.17), (16.0, 0.17), (17.0, 0.17), (18.0, 0.17), (19.0, 0.17), (20.0, 0.17), (21.0, 0.17), (22.0, 0.17), (23.0, 0.17), (24.0, 0.17), (25.0, 0.17)*

*Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)*

Scenario 4a

Alternate Main Model Stocks and Flows:

Residential_Demolition_Fraction = GRAPH(TIME)
(0.00, 1.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Residential_Utility_Demolition_Fraction = GRAPH(TIME)
(0.00, 1.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Scenario 4b

Alternate Main Model Stocks and Flows:

Commercial_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Scenario 4c

Alternate Main Model Stocks and Flows:

Industrial_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Scenario 4d

Alternate Main Model Stocks and Flows:

Commercial_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Industrial_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Residential_Deconstruction__Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Residential_Utility_Deconstruction_Fraction = GRAPH(TIME)
(0.00, 0.00), (1.00, 1.00), (2.00, 1.00), (3.00, 1.00), (4.00, 1.00), (5.00, 1.00), (6.00, 1.00), (7.00, 1.00), (8.00, 1.00), (9.00, 1.00), (10.0, 1.00), (11.0, 1.00), (12.0, 1.00), (13.0, 1.00), (14.0, 1.00), (15.0, 1.00), (16.0, 1.00), (17.0, 1.00), (18.0, 1.00), (19.0, 1.00), (20.0, 1.00), (21.0, 1.00), (22.0, 1.00), (23.0, 1.00), (24.0, 1.00), (25.0, 1.00)

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)

Scenario 5

Alternate Main Model Stocks and Flows:

Commercial_Deconstruction_Fraction = IF TIME = 0 THEN 0 ELSE (0.36(1+0.01)^TIME)*

Industrial_Deconstruction_Fraction = IF TIME = 0 THEN 0 ELSE (0.33(1+0.01)^TIME)*

Residential_Deconstruction__Fraction = IF TIME = 0 THEN 0 ELSE ((0.17(1+0.01)^TIME)-((0.17*(1+0.01)^TIME)*Rehab_Fraction))*

Residential_Utility_Deconstruction_Fraction = 0

Extra_NH_Reuse_Rate = GRAPH(TIME)
(0.00, 1.00), (1.00, 1.00), (2.00, 1.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 0.00), (25.0, 0.00)