Land Quality Division

State of Oregon
Department of Environmental Quality

A Life Cycle Assessment Based Approach to Prioritizing Methods of Preventing Waste from Residential Building Construction, Remodeling, and Demolition in the State of Oregon

Phase 1 Report, Version 1.2

Prepared for DEQ by Quantis, Earth Advantage, and Oregon Home Builders Association

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Phase 1 Report
Version 1.2

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Project Team and Acknowledgements

The project team consisted of Jon Dettling and Dominic Pietro of Quantis; Bruce Sullivan and Bill Jones of Earth Advantage; and Johnathan Balkema of the Oregon Home Builders Association. The Quantis staff conducted the LCA portions of the project. Earth Advantage provided the energy use modeling. The Oregon Home Builders Association provided the modeling of the standard and modified home structures and material lists. Jordan Palmeri and David Allaway of the Oregon Department of Environmental Quality provided valuable insight and information throughout the study. Sebastien Humbert and Olivier Jolliet of Quantis also added input throughout the study. A 50-member external stakeholder panel reviewed a preliminary draft of this report and provided valuable insights and feedback.

Executive Summary

The purpose of this project is to evaluate the environmental benefits of potential actions to reduce materials use and prevent waste occurring in the construction, maintenance, and demolition of residential structures within the state of Oregon. For ease of reference in this report, practices that reduce materials use and subsequently reduce waste generation are referred to as *waste prevention practices*. Although the environmental benefits of these practices appear to be waste related, most of the benefits gained from these practices are through avoided manufacturing and production of materials and the potential of reduced material use increasing the operating efficiency of a home.

In this first phase, the goal has been to effectively evaluate 25 candidate waste prevention practices. The purpose of evaluating these practices is two-fold. The first purpose is to determine which practices prevent waste but are likely to have net negative environmental impacts. The second purpose is to conduct a screening level prioritization in order to identify those practices with the greatest benefits for further study in Phase 2 of the project. A co-

benefit of this approach is that it identifies the parameters and modeling assumptions that are particularly important going into Phase 2. The technique used in this study, life cycle assessment (LCA), takes a broad view of the residential housing systems in question and the range of environmental impacts. An attempt is made to characterize the material consumption, energy consumption, and pollutant emissions occurring throughout the life cycle of the home and extending as far into the material production processes as possible. In this study, the lifespan of the modeled residential home is 70 years. Although climate change impact is the key decision making criteria used, a preliminary assessment has also been made of additional environmental impact categories.

To distinguish among the waste prevention practices, it is essential to establish quality information on the material and energy use over the life of the home. Material use has been established for each practice based on a model of a standard home developed by the Oregon Home Builders Association (OHBA). In addition to providing detailed lists of materials, these home plans also provided input to building energy use modeling conducted by Earth Advantage Institute using the REM/Rate model. A variety of information was gathered to characterize multiple aspects, such as the percentage of material wasted, the replacement of various materials over their lifetimes, transportation logistics, and construction and demolition processes. Quantis – Life Cycle Systems combined this information with data on the environmental impacts of production and/or disposal of various types of material and operational energy use to produce a screening-level life cycle assessment of the 25 candidate practices. In addition to environmental criteria, waste generation and costs were also estimated.

The results of the Phase 1 analysis suggest that the electricity and energy used during the home's occupancy are the dominant contributors to climate change impacts over the life of the home. Production and transportation of the original and replacement materials are also significant contributors, accounting for a combined 16% of the climate change impact. Construction, maintenance activities, and demolition processes are less significant, combining for only 3%. Material handling at end-of-life (specifically recycling and energy recovery from wastes), which was modeled based on the current practices in the state of Oregon, is estimated to recoup 18% of the material production impacts, but only 2% of the total life cycle climate change impact.

Because of the importance of the energy consumption during the use of a home, the best scoring practices are dominated by those that affect a home's energy use and show the most benefit in reducing climate change impacts (see Figure 1). These include the construction and use of smaller homes; multifamily structures; alternative wall materials (including structural insulated panels, insulating concrete forms, and strawbale); durable roofing, siding and flooring; adaptability; design using salvaged materials; and the movement of ducts to a conditioned utility chase. Also included are several scenarios that have a significant impact on the amounts of materials produced and/or disposed, including design using salvaged materials, deconstruction and designing for disassembly. Each of the previously listed practices is estimated in this screening-level study to reduce climate change impacts by at least 38,000 kg of CO_2 equivalents per home, or about 4% of the estimated total. The best scoring option shows potential for a 20% improvement.

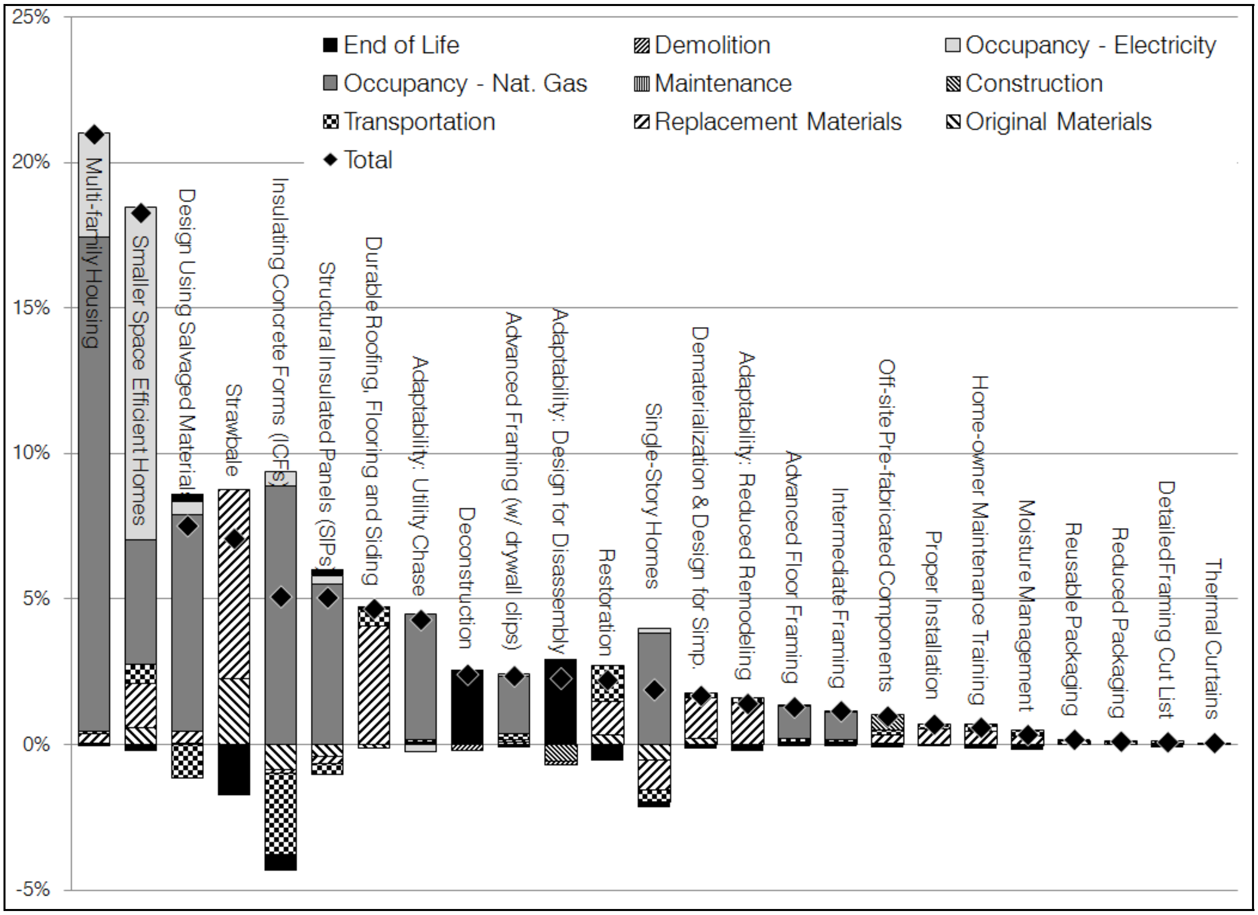

Figure 1: Reduction in climate change impact as a percentage of the total value for the reference Standard Home

Among practices that show limited improvement in climate change score are several options for improving framing of the home, reducing the rate of remodeling, and restoring existing structures. Each of these reduces climate change impact by more than 1% but less than 4% over the life of a home. Many additional practices showed a net benefit for climate change but of less than 1%. These include the use of a detailed framing cut list, the prefabrication of components, flashing and rainscreening, training homeowners, thermal curtains, proper installation, and reducing or reusing packaging. Note that the switch to a single-story home resulted in a net climate change benefit, which may be counterintuitive. This result can be explained by a decrease in area of exterior walls, which are relatively less insulated than the roofs and floors that increase in area. This finding is clearly subject to the assumptions regarding relatively minimal insulation that have been assumed for the baseline home.

The modular LCA technique used in this study has proven to be effective in distinguishing among the candidate waste prevention practices, showing significant differences in climate change benefits among them. It has provided a large amount of valuable information for determining which practices should be studied in more detail in a second phase. There are a variety of important improvements to be addressed in a second phase of the study.

Explanation of Phase 1

This is an intermediary set of results intended to support a larger assessment of waste prevention options for residential buildings within the state of Oregon. The purpose of this first phase is to efficiently shorten a list of candidate practices to identify those of highest priority for conducting a more detailed life cycle assessment in Phase 2. Therefore, the scope and depth of this analysis have been limited in many aspects that were deemed to be less crucial and it is recognized that significant uncertainties remain. *In drawing conclusions, the reader should recognize the need for further improvements in many areas of the study.* The second phase of this study is expected to address many of the key areas of uncertainty and will be completed by the beginning of 2010.

I. Introduction

Project Background and Context

Oregon has a long history of progressive environmental legislation, including a first-in-the-nation state land use plan to prevent sprawl and preserve resource and farm lands, its bottle bill, efforts to address global warming, and its waste management and waste prevention activities. With respect to waste management, existing statutes (e.g., ORS 459.015) place waste prevention above all other methods as the first priority in managing solid waste, followed by reuse (ODEQ 2006).

Growth in the quantity of waste generation has been of increasing concern to the State of Oregon. Oregon defines *waste generation* as the sum of materials recovered (recycled, composted, and, in some cases, burned for energy) and materials disposed of (via landfill and waste combustion units). It is a total of all materials discarded, and a crude measure of materials consumption. Published data from that department indicates that between 1993 and 2005, there has been a 70% increase in solid waste generation in Oregon. On a per capita basis, waste generation increased 43% during this same time period (ODEQ, 2007).

Analysis by DEQ indicates that while some of this increase is a result of better measurement and shifts in how materials are discarded (away from "non-counted" methods, such as home burning, and towards "counted" methods, such as recycling and centralized composting), an estimated 50-80% of the increase is likely attributable to real increases in waste-generating activities and materials use. That is, Oregon residents and businesses, in total, in recent years have been consuming and discarding more materials than in the early 1990s. While one result is that landfills are filling up faster than anticipated, a greater environmental concern is the impacts associated with production (and in some cases, use) of these increasing quantities of materials.

Furthermore, DEQ has found building construction, remodeling, and demolition activity to be a major contributor to materials use and waste generation. In a 2007 study, DEQ found that not only are construction, renovation, and demolition debris a significant solid waste source but that they will remain so for some time into the future.

> Because most building-related waste results from renovation and demolition activities (as opposed to construction), the majority of building materials consumed don't end up as wastes until years or decades after construction. Today's building wastes are largely materials that were purchased and installed years or decades ago. (ODEQ, 2007)

Guidelines

Oregon DEQ recognizes that a successful waste prevention program must take an approach based on life cycle analysis (LCA). Both *upstream* (resource extraction and production of goods) and *downstream* (end-of-life/waste management) impacts need to be addressed, as do impacts occurring in the use of a product or system. This perspective is necessary for DEQ to achieve the three objectives from its Waste Prevention Strategy (ODEQ, 2007):

Environment – Strategically reduce GHG emissions, waste generation, and environmental impacts.
Sustainability – Demonstrate that preventing waste can have a positive economic, social, and environmental impact, and that prevention is a relevant component of a sustainable society by addressing the broader impacts of materials, product use, and design.
Waste Generation – Take strategic actions that prevent waste generation and contribute to achieving Oregon's waste prevention (generation) goals established in state law.

Oregon DEQ defines waste prevention as those activities that prevent the generation of solid waste in an environmentally beneficial manner. Waste prevention includes using fewer materials and the reuse of materials. Recycling, composting, and energy recovery do not prevent the generation of solid waste and are therefore not considered waste prevention activities.

While this project does not seek to specifically identify the benefits of recycling practices or the use of materials with recycled content, it does consider current recycling practices as part of the modeling exercise. The current recycling rates for various construction materials in Oregon can be viewed in Appendix Table 13.

The project is guided by three main tenets:

1) Given the wide range of possible actions, resource limitations necessitate that well-informed policy decisions are made and that *the most effective measures are chosen* and *those of negligible or even negative impacts are avoided*.
2) Decisions that promote solid waste prevention have impacts that range far beyond the generation of waste to include climate change, energy use, resource use, human health, and ecological health. Therefore, ensuring that all actions achieve a net

environmental improvement requires a decision framework that accounts for *impacts of the building sector within all categories of environmental impact*. There will also be tradeoffs among phases of a home's life; actions that may lead to benefits in materials production or construction could have adverse impacts during the occupancy of the home and vice versa. Therefore, it is necessary to have a decision framework that properly accounts for the full impacts of residential buildings *over their entire life cycles*.

3) It is acknowledged that in many cases, actions will not lead to clear benefits at every point of a home's life or within every environmental impact categories. There will therefore be tradeoffs that must be considered. While there may not be clear scientific guidance that can be provided to definitively justify such tradeoff, the scientific approach of LCA will *allow the nature of these tradeoffs to be made clear and transparent*.

II. Project Goals and Approach

The ultimate goal of the project is *to support decisions by the Oregon Department of Environmental Quality and others in their efforts to form programs, policies, and actions to prevent waste generation from the residential building sector in a way that maximizes overall environmental benefits.*

This Phase 1 report makes substantial progress towards the project goal by achieving the following more specific objectives of the project:

- Identify and characterize those building practices that are likely to prevent waste from the residential building sector.
- Efficiently screen these methods to determine those which are most likely to provide the greatest environmental benefit across a range of impact categories and from a life cycle perspective.

Approach Overview

The project takes a tiered approach of first cataloguing and characterizing the available options (Phase 1); then screening these options based on a simplified single-home LCA model to eliminate those that are unlikely to pose a high environmental benefit relative to the others (Phase 1); and finally conducting a more thorough analysis, including both single-home and population-based LCA models to compare the remaining options (Phase 2).

The major project emphasis will be on Phase 2, where the quality of the whole-building LCA presented here will be improved upon in several respects and the single-building results will be expanded to represent the housing stock of the state as a whole. This LCA has followed the international standards in the field, which are contained in the ISO 14040 and 14044 documents, with the exception that an external peer review will not (under the current work plan) be conducted on the results. The ISO standard states that for a study containing comparative assertions intended for public disclosure, such a review should be conducted. It should be noted that the scope of the present study is to be able to compare large-scale actions or policies by the state of Oregon, rather than to achieve highly accurate and reliable comparisons among specific materials or building products.

The study has been based on the best available information derived thorough assessment of data quality and balancing factors, such as geographic relevance, temporal relevance, scientific credibility, and internal study consistency.

Waste Prevention Practices

The waste prevention practices that are assessed in the present study are listed below. The list of 25 practices was generated by DEQ staff through a literature search and in consultation with numerous residential building professionals in Oregon. While the list may not be exhaustive in covering every residential waste prevention practice possible, it does cover a substantial number of practices in the design, construction, remodel, and demolition of residential homes.

1. Intermediate Framing
2. Advanced Floor Framing
3. Advanced Framing (w/ drywall clips)
4. Detailed Framing Cut List
5. Offsite Prefabricated Components
6. Adaptability: Design for Disassembly
7. Adaptability: Utility Chase
8. Adaptability: Reduced Remodeling
9. Flashing and Rainscreening
10. Deconstruction
11. Durable roofing, siding and flooring
12. Design using Salvaged Materials
13. Homeowner Maintenance Training
14. Proper Installation
15. Restoration
16. Multifamily Housing
17. Smaller Homes
18. Insulating Concrete Forms
19. Structural Insulated Panels
20. Strawbale w/ timber frame
21. Thermal Curtains
22. Reusable Packaging
23. Reduced Packaging
24. Dematerializing and Design for Simplicity
25. Single-story Homes

Each practice is described in more detail in its Report Card, contained in Appendix 2. An explanation of the report card format is provided in Appendix 1.

Functional Unit

For the LCA performed in Phase 1, the functional unit is *the provision of 70 years of single-family housing*. The 2000 U.S. Census placed the average household in Oregon at around 2.5 occupants and the baseline scenario considered here is intended to represent the typical Oregon household. However, the number of occupants is not used as a direct determinant of any of the results and therefore the results will be equally applicable to the accommodation of more or less people within the same structure.[1] The study includes the production and manufacture of all materials comprising the structure of the home (including the original and replacement materials), the transportation of

[1] A possible exception to the lack of influence of occupant number is the non-HVAC energy. Although the number of occupants is not used as an input to REM/Rate in determining this value, it can reasonably be expected that more or less occupants would use a greater or lesser amount of electricity.

these materials to and from the site of the home, the construction of the home, maintenance of the structure, the use of the home, its demolition, and the management of all waste materials. Consideration of the use of the home is limited to energy use (including all fuel and electricity for heating, cooling, and other purposes, such as lighting and plugged-in appliances or devices). In the present phase, there are no attempts to also account for any other aspects of occupancy that might have a link to the home's design or construction as determined by the practices under consideration.

The selection of 70 years as an average life is a highly uncertain number. While establishing the average life of past and existing homes is difficult, predicting the lifespans of homes built today is even more difficult. The selection of 70 years has been validated by a brief check of the American Housing Survey data, which suggests that the average annual rate of loss of homes in the Portland area ranges from 0.5% to 2%, depending on the decade of their construction (indicating an average life of 50 to 200 years). Because of the uncertainty and potential importance of this number, it is one of the factors selected to undergo a sensitivity analysis, which is presented in Appendix 6.

III. Methodology

Phase 1: Screening of Potential Actions

In Phase 1, the potential waste prevention and environmental impacts from building activities have been evaluated using a life cycle assessment (LCA) model. The purpose of this phase is to efficiently screen the list of waste prevention practices to determine those with greatest potential to prevent waste and provide overall environmental benefit. In addition, it is desired to identify those that have significant remaining uncertainties that warrant further consideration. Rather than providing definitive conclusions, the purpose of Phase 1 is to inform the selection of a subset of practices that will be evaluated in greater detail in a second phase of the project.

Exclusion of practices from Phase 2 does not necessarily indicate that they are not worthwhile practices to pursue or that substantial benefits might be obtained from them. It should be considered that the impacts of the housing sector are quite large and even an improvement of a few percent is a very substantial improvement when considering all housing in the state.

Throughout the Phase 1 assessment, decisions have been made to strategically simplify or expand the level of detail to provide a balance of accuracy and efficiency. Emphasis has been placed on eliminating practices from further consideration as efficiently as possible while minimizing the risk of false negatives. Using LCA in Phase 1 is crucial because it introduces a level of rigor and quantification that minimizes errors that might otherwise occur using common wisdom, qualitative assumptions, or some other general screening process. Nevertheless, the LCA-based calculations in Phase 1 have limits in their quality and the consistency of treatment of each practice. For example, the scenario of switching from multistory to single-story home has been carried out with just one set of assumptions and it is apparent that the results are highly sensitive to the relative insulation efficiencies of the roofing, floors, and walls. The results for that practice are therefore illustrative of an example but not necessarily indicative of all such scenarios.

This Phase 1 analysis has been conducted with a focus on a single-family residential home. The evaluation of each building practice incorporates a combination of existing data and information that has been gathered from primary and secondary sources, as well as the team's expert judgment and opinions in cases where no reliable information could be obtained. Table 1 lists the main areas in which relatively subjective decision or judgments have been made. The resulting baseline home scenario is intended to represent a typical, not optimal, new construction home in Oregon. There are many possible formats for such a typical baseline home. While it is acknowledged that alternative baseline layouts could somewhat modify the results of the present study, it is not possible to quantify the magnitude of this influence on the study. It is assumed that the conclusions of the study are not sensitive to layout variations within the range of typical homes (with the significant exception of single-story/multistory structures mentioned above). Table 1 lists key areas in which subjective judgment has been used. In some cases, improvements may be made in Phase 2 through gathering of more data. In other cases, such judgments are an inherent part of such a study.

Table 1: Key areas in which subjective decisions have been made

Topic area	Basis for decision or judgment
Selection of waste prevention practices	The experience of Oregon DEQ's staff in investigating potential options for reducing waste from the residential construction sector.
Design of standard home	Expertise of Oregon Home Builders Association regarding current building codes, practices and trends in Oregon, complemented by expertise of Earth Advantage and ODEQ in these area.
Design specification of implementing practices	Expertise of OHBA and EAI in common green building practices applied in Oregon. Expertise of OHBA in home design.
Choice of where to exchange detail for efficiency in screening-level Phase 1 LCA	Expertise of Quantis – Life Cycle Systems in assessing complex systems with an LCA approach.
Assumptions for activities of workers and machinery during construction, maintenance and demolition	Rough approximations confirmed by the experience of OHBA in residential home building.
Transportation distances of materials to the building site	Approximation made based on experience in examining various transportation networks.

A Report Card has been prepared for each building practice. Report Card content includes succinct evaluations for a range of key criteria to be used to evaluate the waste prevention and environmental potential of each building practice. An explanatory section describing the Report Card content is included in Appendix 1 and the Report Cards themselves are contained in Appendix 2.

The evaluation of the practices includes a combination of three models: a CAD-based model of the building structure created by the Oregon Home Builders Association to represent a standard Oregon home and inform decisions on the implications of building practices on material use; REM/Rate, a commercially available software capable of estimating home energy use based on a wide variety of inputs regarding the home's structure, geography, and numerous other factors; and a customized LCA-based calculation system created for this project in MS Excel. Supporting LCA work was conducted in the SimaPro commercial LCA software.

A more detailed description of each of the three modeling stages in the assessment is provided in Appendices 3, 4, and 5, along with a wide variety of the underlying assumptions and sources for information.

Characteristics of the Standard Home

The analysis presented here is based on a theoretical home whose characteristics have been selected to represent a relatively standard new construction home in Oregon, representing a home of average size, and meeting the minimal Oregon building code requirements. The *standard home* created here has an interior area of 2,262 square feet (210 square meters), which is slightly under the average size of a newly constructed single-family home.[2] The standard home was modeled as a baseline to which all waste prevention practices can be evaluated against. Thus, all environmental benefits or impacts of any given waste prevention practice are relative to the environmental performance of the standard home.

Attempts have been made to make the standard home reflect the most typical current practices, with the exception of excluding practices from the standard home that will be evaluated within the project. For example, even though the framing practices represented as Intermediate Framing (practice 1) are as common or more common than those practices used in the standard home, the minimal code requirements have been used as the standard so that Intermediate Framing can be compared against those practices as part of the evaluation. The OHBA's modeling (see Appendix 14) has provided detailed floor plans and lists of necessary materials to construct the standard home.

Figure 2 shows a view of the exterior of the standard home, while Figure 3 shows the layout in the interior. Table 2 lists several key characteristics of the standard home.

Figure 2: Exterior view of the standard home used in this study

[2] The U.S. Census reports that in 2008, the U.S. average for new home construction was 2,534 square feet (www.census.gov).

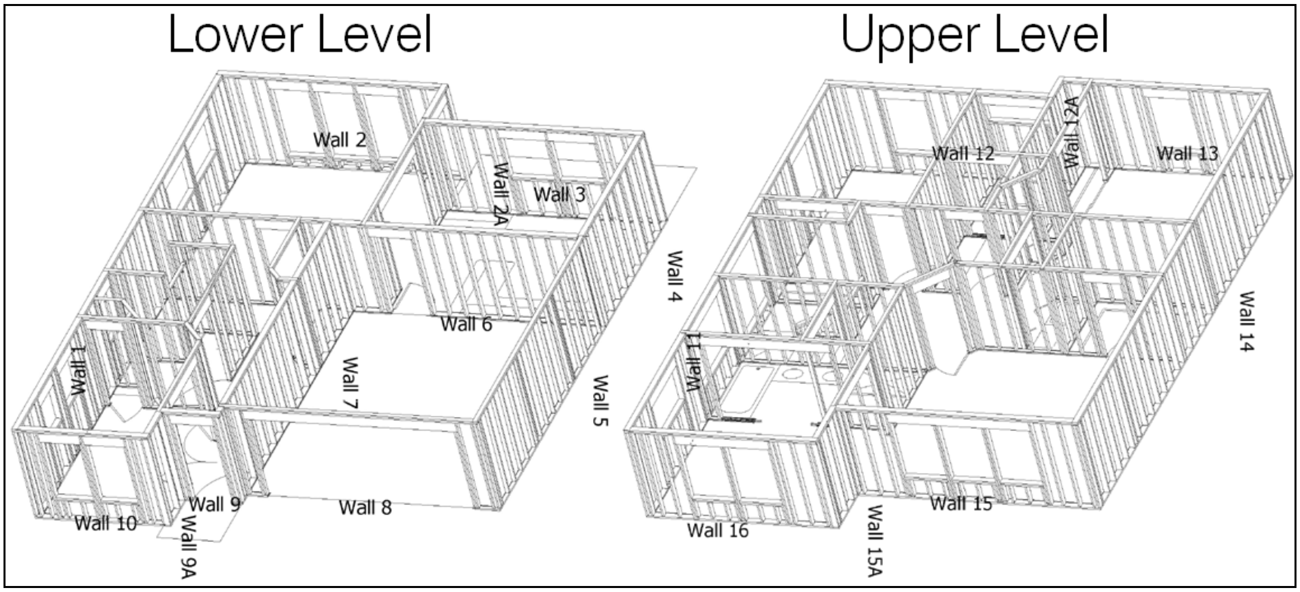

Figure 3: Interior view of the standard home used in this study

Table 2: Characteristics of the standard home used in this study

Interior Size	2,262 square feet
Exterior Dimensions	33' x 35'
Stories	2
Garage	Yes, attached
Foundation	Vented crawl space
Conditioned Building Volume:	20,358 cubic feet
Bedrooms	3
Bathrooms	2
Framed Floor Insulation	R30 fiberglass
Walls Insulation	R21 fiberglass, framing factor 26%
Ceiling Insulation	R38 fiberglass
Windows	Double-glazed, low-e, vinyl frame, U-0.35; 374 sq ft of windows, minimal solar gain orientation
Doors	2¼" solid wood, R2.8
Heating	90% efficient gas furnace
Water Heating	58% efficient gas storage tank
Building Standards	Oregon building code minimum
Air Conditioning	None
Flooring	2,000 square ft carpet, 200 square ft linoleum
Roofing	Asphalt Shingles
Roof Truss	Built without raised heals
Duct Leakage	RESNET/HERS default, all leakage outside of thermal envelope
Building Air Leakage	6.5 ACH@50 Pascals
Siding	2124 square ft of wood siding
Lifespan of House	70 years
Walls	92-5/8" studs; 8'-1 5/16" height; single

	sole/double top plates, headers on all
Floor Framing Style	Post and beam
Floors	4x8 beams, plywood subfloors
Wall Interiors	Drywall
Appliances Modeled for Material Production Impacts in Phase I	Furnace, Refrigerator, Stove, Dishwasher, Air Conditioner, Water Heater
Plumbing	PEX

Additional materials have been added to the home material inventory to represent a typical new construction home at the time of its first occupation (and that would typically be transferred to the new owner during subsequent sales). For example, finish carpentry, electrical and plumbing fixtures, flooring, paint, and major appliances are included while couches, tables, decorations, or other possessions of the occupants are not included. With the exception of attached structures (including a garage and porch), no external structures or aspects of the home's yard are considered.

The outputs of the OHBA model have been used to parameterize REM/Rate, which is then used to assess the home's annual energy usage. The energy usage is estimated to include heating/cooling energy, water heating, lighting, appliance energy, and all other uses of electricity. It is assumed that the standard home has a natural gas furnace with forced hot air heating and no air conditioning.

REM/Rate provides estimates of the average annual energy use of the home and, very importantly, is able to account for differences in the energy use based on many of the practices that have been evaluated here. As prior LCA results on housing have indicated that the majority of environmental impacts occur from the use of energy during occupation, an accurate system for determining differences in energy use is critical for the present study. Further details on the selection and operation of REM/Rate are included in Appendix 4 and from the Web site of the software developer.[3] While REM/Rate is not without its faults, it is the experience of Earth Advantage (a national leader in home energy rating) that other available options have as many or more uncertainties. Recent benchmarking by Earth Advantage suggests that REM/Rate is sufficiently accurate for new construction, which is the focus of this first phase.

The building material lists provided by the OHBA model and the energy use provided by REM/Rate have been used to parameterize the building practice scenarios within the LCA modeling framework. The LCA model has been constructed to represent the total environmental impacts of producing all materials used in building and maintaining the home, transporting these materials to and from the home's location, the energy use of the home's occupants, the maintenance of the structure, its demolition, and the end-of-life processing of the materials. This is done by linking material, energy, and process inventories for the home with preexisting or modified data that represent the impacts of producing, using, or disposing of materials and energy.

It is important to note that this study does not consider any impacts associated with the direct occupation of land area by the home (such as on fragmenting or limiting wildlife habitat), impacts associated with daily transportation of the residents, or any indirect effects through development patterns (such as additional traffic congestion and utility infrastructure).

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[3] Architectural Energy Corporation, www.archenergy.com

The modeling done in this study has been conducted to maximize applicability within the state of Oregon and it should be noted that the assumptions made may mitigate the usefulness of applying the results in other geographies. The housing design is based on current practices and codes within Oregon; the energy modeling is based on typical Oregon climate. In addition, many sources of data have been selected with an intention that they would be highly representative of Oregon, including, for example, the rates of waste disposal routes for various materials, the waste-to-energy processing of wood, wood product production, energy costs, home maintenance rates, and others. While some conclusions may be broadly applicable, the reader should recognize that others may be less applicable beyond Oregon conditions.

Boundaries and Stages of the Home's Life Cycle

The boundaries of the study are intended to include all impacts within the production chain of the materials, energy, and processes that comprise the home's life cycle. For example, in calculating the CO_2 emissions from the combustion of natural gas, not only the direct emissions from the furnace are considered but also those emissions occurring in the production of the gas. Similarly, the inclusion of lumber for the home includes all process in the lumber production,[4] including the forestry activities and the production of the materials and fuels used in forestry

To provide a numerical example of the impact of this scope, for each kilowatt-hour of electricity used by the homeowners, the methodology used here results in a total use of about 3.5 kilowatt-hours of nonrenewable energy to provide that electricity to the home (accounting for generation and transmission losses as well as the energy required to produce the fuels used for electricity generation).[5] This broad scope is one of the primary values provided by LCA and avoids the possibility of selecting actions that simply shift environmental burdens elsewhere in the economy.

The life cycle of the home has been divided into the stages listed below. The relationship of the stages, their timing, and the aspects that are included are depicted in Figure 4. Note that the stages do not necessarily represent a time sequence, although several stages (e.g., construction and demolition) are confined to a specific time point. For example, throughout the home's life, materials are produced and disposed of. The materials production is divided into two components, one representing the original materials and one representing the replacement materials. The *Material*

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[4] The information used to represent the production of most wood products has been represented based on data from the Consortium for Research on Renewable Industrial Materials (CORRIM, www.corrim.org). This information was assembled based on the growth of wood in the Pacific Northwest and Southeast United States. Where there is an ability to select among these geographies, the Pacific Northwest data has been produced. No specific forestry practices or certification procedures have been indicated to be the focus of the project producing this information. It is therefore assumed that it represents the typical wood and wood product production in those regions. It is not known how the results might vary under alternative forestry conditions, such as the use of forestry products certified to be raised with certain practices or forestry products from other geographies where growth conditions could be substantially different.

[5] For example, looking at coal-derived electricity, each kilowatt-hour of electricity supplied to a home requires the mining of about 0.47 kg of coal. This amount of coal has an energy content of about 3.3 kilowatt hours (with substantial variation depending on the coal). Further energy is used, perhaps 0.1 kilowatt-hour, to process and transport the coal to the plant. A further 0.1 kilowatt-hour may be used in operating the plant. Because the electricity production is not perfectly efficient, there are significant losses of energy content during the electricity production, resulting in perhaps only 1/3 of the coals energy content leaving the electrical plant as electricity. Of these 1.1 kilowatt-hours of electricity that leaves the plant, a further 0.1 kilowatt hour is likely to be lost due to inefficiencies in the transmission lines and in transforming it to the voltage needed for home use. The result is that when considering the full life cycle of the supplies to the home, a much larger scope is captured than what is apparent at the site of the home itself. This full scope is necessary to accurately compare the true impacts of changes in building practices (information drawn from the ecoinvent database).

End-of-Life stage includes the disposal, treatment, or reuse of materials disposed of at the beginning of the home's life, as well as during maintenance and at demolition.

Aspect	Pre-occupancy	Occupancy	Post-occupancy
Extraction of original raw materials Refining raw materials Manufacture of products Production of packaging All transportation occurring upstream of the final production site	1. Production of Original Materials	2. Produciton of Replacement Materials	
Transportation of materials from the production site to the site of the home	3. Transportation		
Operation of heavy machinery Use of electricity by construction, maintenance or demolition activities Transportation of construction workers to and from the home site	4. Construction	5. Maintenance	8. Demolition
Electricity use by the homeowners		6. Occupant Electricity	
Natural gas use by the homeowners		7. Occupant Heating Fuel	
Transport of materials from the site Landfilling of materials Recycling of materials Incineration and/or energy recovery Reuse of materials	9. End-of-Life		

Figure 4: Aspects represented in each stage of the home's life cycle

Data and Information Sources

Data collection has focused on preliminary characterization of the standard home and each waste prevention measure. A literature search has been conducted to identify a wide variety of potential sources of information for the study. The resulting references are listed in the bibliography (Appendix 17). The literature review provides a solid basis of available information to identify necessary parameters and benchmark results. It has been drawn on in conducting the Phase 1 assessment to provide the level of detail needed for efficiently making decisions.

To support the LCA modeling, a variety of information has been collected from the literature review, database searches, team expertise, vendor product data, and interviews with experts, among other sources. This data includes information on material sizes and densities, costs, residential building characteristics, material replacement rates and causes, material waste amounts and processing, transportation logistics, and aspects specific to many of the scenarios examined, among other information.

Where data was either unavailable or incomplete, professional judgments or estimates were made by team members who have expertise in the residential building sector. Examples of areas where this was done are listed in Table 1. The sources of data used are detailed in Appendix 10.

Impact Assessment Methodology

The primary impact assessment methods applied include a climate change impact assessment (based on the IPCC 2007 GWP weighting with biogenic carbon dioxide excluded)(IPCC, 2007; BSI, 2008), and assessments of nonrenewable energy use, resource depletion, human health, and ecosystem quality (each based on the IMPACT 2002+ method from Jolliet et al., 2007). As a sensitivity test, the Tool for the Reduction and Assessment of Chemical Impacts (TRACI) system has also been applied. The majority of the data shown in this report are for the climate change impact. These data are presented as kilograms of carbon dioxide equivalents (kg CO_2 Eq.), which is a unit reflecting the estimated impact on global climate change of all greenhouse gasses emitted. See Appendix 5 for additional details of the impact assessment methods used. The sensitivity test performed on impact assessment metrics suggests that while in most cases the other impact categories are directionally consistent with climate change impacts, there are notable exceptions. Therefore, climate change impacts should not be interpreted as an indicator of overall environmental performance without adequate regard for these other impact categories.

Example Calculation

The following table shows an example calculation to illustrate how the various information sources are combined within the LCA to produce impacts on the net benefit or impact of each scenario. This example shows the impacts in one environmental impact category of the emissions of one substance to one environmental compartment from the production of one type of material within the home to calculate the net impact for one of the building practices. To compute the overall results, such calculations need to be carried out for: 1) each of the materials or energy uses in the home's life cycle; 2) each of the pollutants emitted to each environmental compartment (e.g., air, water, soil); 3) each of the impact categories considered; and 4) each of the building practices being modeled.

The impacts are calculated by first identifying the amount of the material in the home. This information is determined based on the modeling of the home's structure, contents, and energy usage. This information is multiplied by an emission factor that indicates the amount of a pollutant emitted in producing that product or supplying that energy. In the case of resource consumption, it is a factor for the amount of resource used rather than pollutants emitted. This information is gathered from existing data sources as described in the above section. The multiple of these two provides the amount of that pollutant emitted in producing that material.

Impact assessment can then be applied to the emissions of pollutants. The methods used here provide factors that can be used to evaluate the importance of emissions of various substances. These factors are multiplied by the amount of each substance emitted to determine the impact of emissions of that substance. To determine the impact of the house as a whole, this must be carried out for each material or energy use within the home and for each pollutant or resource usage for which there is available information for its inclusion.

The net impact or benefit of the scenarios is then determined as the difference in the total among the impact caused by each of the components of the home's life cycle.

Table 3: Example calculation of the ecotoxicity impacts associated with the emissions of lead to air caused by the use of glass wool insulation in the standard and smaller home scenarios.

	Item of Information	Unit of Measure	A Standard Home	B Smaller home	How Information is calculated or determined

1	Amount of glass wool in life cycle of home	kg glass wool	6874	4792	Determined based on home design and density of material
2	Amount of lead emitted to air per kg glass wool	mg lead / kg glass wool	0.95	0.95	Taken from preexisting data sources regarding the production of glass wool; in this case, the ecoinvent database
3	Total amount of lead emitted to air in producing glass wool for home (g)	g lead	6.53	4.55	Line 1 multiplied by line 2
4	Impact of lead emission to air on ecotoxicity	g 2,4-D equivalents per g lead emitted to air	1.44	1.44	Taken from the documentation of the appropriate impact assessment method, in this case the TRACI ecotoxicity method
5	Impact of producing the glass wool for this home	g 2,4-D equivalents	9.40	6.56	Line 3 multiplied by line 4
6	Net ecotoxicity impact from lead emission to air of added glass wool insulation for multifamily housing	g 2,4-D equivalents	-2.85		Item B5 minus item A5

Uncertainty

Before considering the results of the study, it is important to convey an understanding of the certainty of the information presented. Uncertainty enters the calculations that have been made at each stage. This includes the estimation of the amount of material or energy that is used, how this differs among scenarios, the impacts of producing these materials, their rates of replacement, the processes of constructing and demolishing the home, and the handling of materials at end of life. In addition, because the goal is for the results of the assessment to reflect broadly on a diverse set of housing structures in the state of Oregon, there is also uncertainty in assuming that the findings are indeed representative of all or most structures in the state. While a formal uncertainty assessment has not been conducted at this stage, it is clear that the uncertainty of the overall estimation of the environmental impact of a home over a 70-year life is significant.

Fortunately, the uncertainties in comparison among the practices are likely to be much less than the uncertainty in the results as a whole. This is because many of the key areas of uncertainty in the results are the same among the building practice scenarios because they are based on similar data or assumptions. For example, if the climate change impacts of the use of electricity were underestimated, using a higher value for this would increase the impact assigned to all the building scenarios in proportion to their use of electricity. The comparison among scenarios would therefore shift by a much lesser amount than the results for the scenarios in isolation. Because most areas of uncertainly are linked to some extent, the uncertainty in the conclusions is less than it might seem from simply considering the uncertainty in each parameter that is included.

There are methods for formally quantifying uncertainty in such a study. However, they are quite complicated and even more so in a study as broad as the present one. There has therefore not been an opportunity to apply a formal uncertainty assessment to the present phase. In the absence of such an assessment, the reader should use caution in drawing conclusions when comparisons of practices are quite close. Differences of several-fold or more might safely be considered to be real. Differences of 50% or less among the impacts of practices should certainly be looked at with caution and might be considered equivocal. Fortunately, the spread between the best and worst performing tiers of practices is between 10-fold and 100-fold, suggesting that many conclusions can be regarded with a reasonable level of certainty.

Although a first phase of the study, the analysis that is presented here is in many ways at or near the level of the best available building-related LCAs. In some cases where it has been deemed necessary for the purposes of this first phase of the assessment, such as in the quantification of materials and energy use, the present study contains a very high level of detail and accuracy, matching or exceeding what is generally available in the building LCA literature.

Finally, it should be noted that the study has been constructed with the intention of addressing its goals, which are to evaluate building practices and related policies or programs of action. Answering other or more detailed questions might require a different scope and/or more detailed study.

IV. Phase 1 Results

Overview of results for the standard home

The total climate change impact over the life cycle of the standard home are shown in Figure 5.

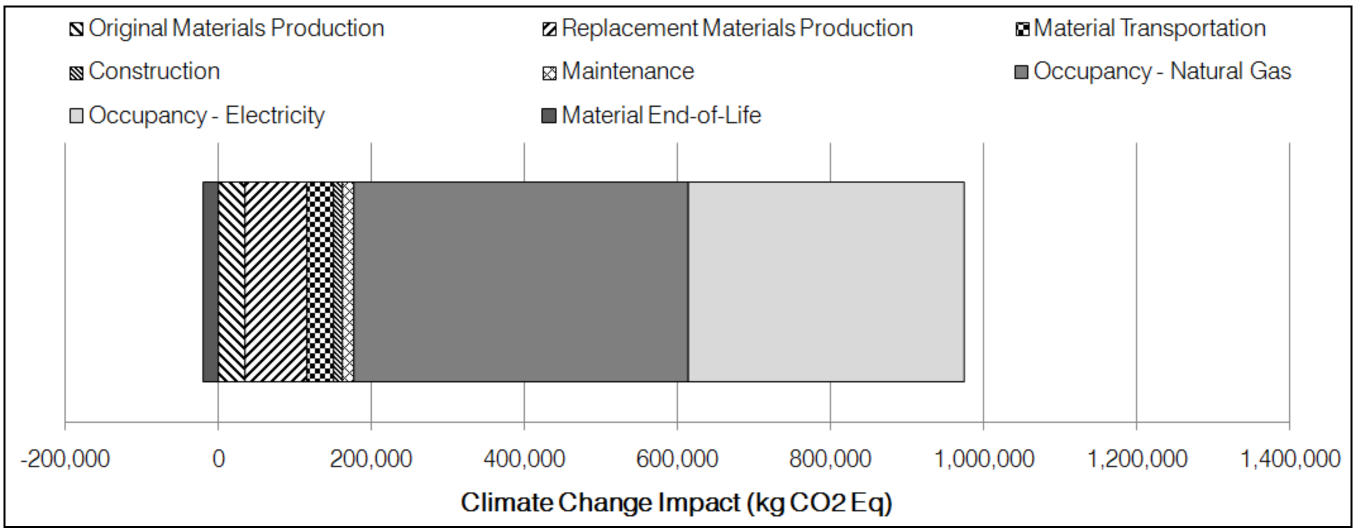


Figure 5: Climate change impact for the standard home by stage of the home life cycle

The use of the home (occupancy heating fuel and electricity) is clearly the most prominent stage in the life cycle, contributing in excess of 80% of the total climate change impact. The materials production stages (including original and replacement materials) contributes a significant amount of the remainder, at 12% overall, followed by *Transportation* at 4%. The *Construction*, *Maintenance,* and *Demolition* phases contribute only a small amount to the climate change impact, while the end-of-life of materials results in a small net benefit in climate change.

It should be noted that both the total magnitude of the home's impacts and the relative distribution among stages are highly dependent on the life of the home (assumed here to be 70 years). While the use phase of the lifecycle is entirely proportionate to the lifetime, other stages are also affected by the lifetime but to a lesser extent. For *Materials Production*, *Transportation,* and *End-of-Life*, for example, about 55% (by weight) of the materials in question are produced for the home's original construction and the remaining 45% are used to maintain the home over its 70 year life.

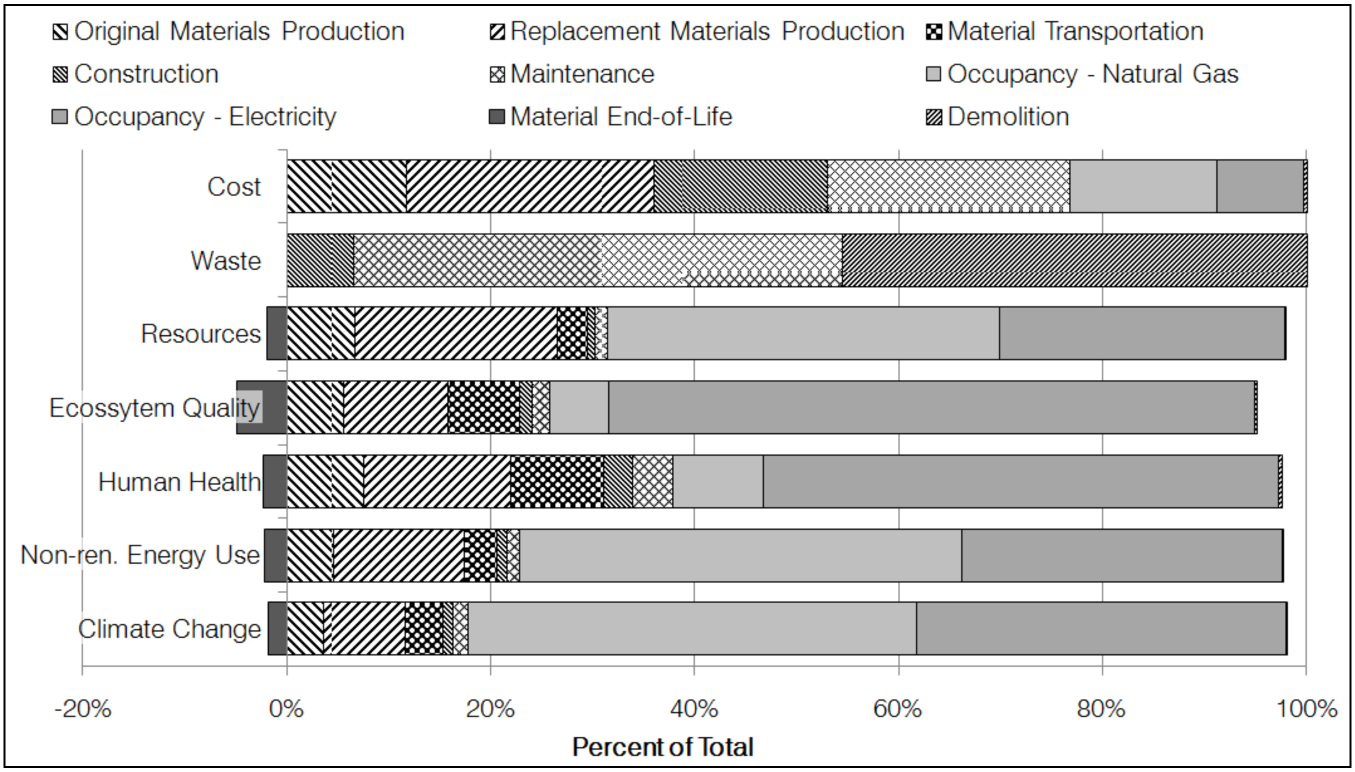


Figure 6: Percent of costs, waste generation, energy use and resource scarcity, human health and ecosystem quality impacts by stage of the life cycle for the standard home

As with climate change, the *Occupancy* stages of the life cycle are the most significant contributors to each of the other impacts considered, with *Material Production* phases as a distant second, followed by *Transportation*. For Ecosystem Quality and Human Health, the *Transportation* and construction-related phases provide a more significant impact than for other impact categories, reducing the contribution of the use phase to roughly 2/3 for Human Health and 3/4 for Ecosystem Quality. This is due to the importance of the emissions from the machinery and transportation vehicles to these impact categories.

The costs that have been assessed are intended to represent only those born by the home's occupants. Cost has not been the primary focus of this study and the cost modeling is intended to be a rough approximation (see more description of cost calculations in Appendix 5). For costs, the materials production stages together contribute slightly more than one-third of the total, with the construction/maintenance phases also adding slightly more than one-third. The energy use provides the majority of the remainder, at just less than 25%.

The waste generation is roughly split between those materials disposed of during *Maintenance* events and those disposed of at the *Demolition* of the home, with 5% of the total occurring at the time or original construction. This suggests that many of the waste prevention practices examined here may have a long delay between their implementation and the realization of the reduction in material entering the waste stream.

Within the use phase, the climate change impacts are split between the consumption of natural gas for heating (contributing 55% of the total) and the use of electricity (45%). While the combination of these two dominates each of the impact categories considered, their ratio relative to each other varies significantly by type of impact.

The contribution of individual materials to the climate change impact (including their production, transportation, and end-of-life) are shown in Table 1. Figure 9 shows the same information graphically. The amount of each individual material with the listed categories is provided in Appendix 9.

Table 4: Climate change impact (kg CO_2 Equivalents) for material production, transportation, and end-of-life by material for the standard home

Item	*Mass*		*Climate Change Impact (Kg CO2 Eq.)*					
	Original Mass (Kg)	*Replacement Mass (kg)*	*Material Production*	*Transport*	*Recycling*	*Landfilling*	*Waste-to-Energy*	*Total*
Flooring	472	3,622	29,366	1,228	(660)	340	300	30,574
Roofing	4,723	14,233	19,366	5,685	(532)	399	(248)	24,670
Drywall	11,167	12,347	8,050	7,053	(204)	303	0	15,202
Insulation	2,062	4,812	10,271	2,062	0	84	0	12,417
Foundation	21,244	0	4,810	6,372	(383)	301	(107)	10,993
Appliances	900	4,410	14,861	1,593	(7,430)	0	0	9,023
Lumber / Wood	17,146	11,321	8,219	8,145	(174)	504	(8,875)	7,817
Siding	1,025	3,585	6,043	1,383	(177)	254	(764)	6,739
Electrical / Plumbing	508	453	5,439	288	(27)	18	9	5,728
Doors / Windows	1,268	2,405	4,773	1,102	(21)	67	(515)	5,407
Packaging	544	0	1,584	163	(70)	82	36	1,796
Paints / Adhesives	52	397	1,046	135	(377)	2	73	879
Hardware	239	177	923	125	(134)	1	0	914
Ducting	230	110	755	102	(110)	1	0	748

The materials contributing most to the climate change impact include flooring (the standard home has carpeting and linoleum flooring), roofing (asphalt shingle), drywall, appliances, insulation, and lumber. Combined, these materials contribute ¾ of the total climate change impact. The addition of foundation, siding (wood), doors (aluminum exterior, wood interior), window, plumbing, and packaging bring the total to 98%. Paints, adhesives, ducts, and hardware are shown to contribute only a minimal amount.

The climate change impacts of the processes of *Construction*, *Maintenance,* and *Demolition* are shown in Figure 7.

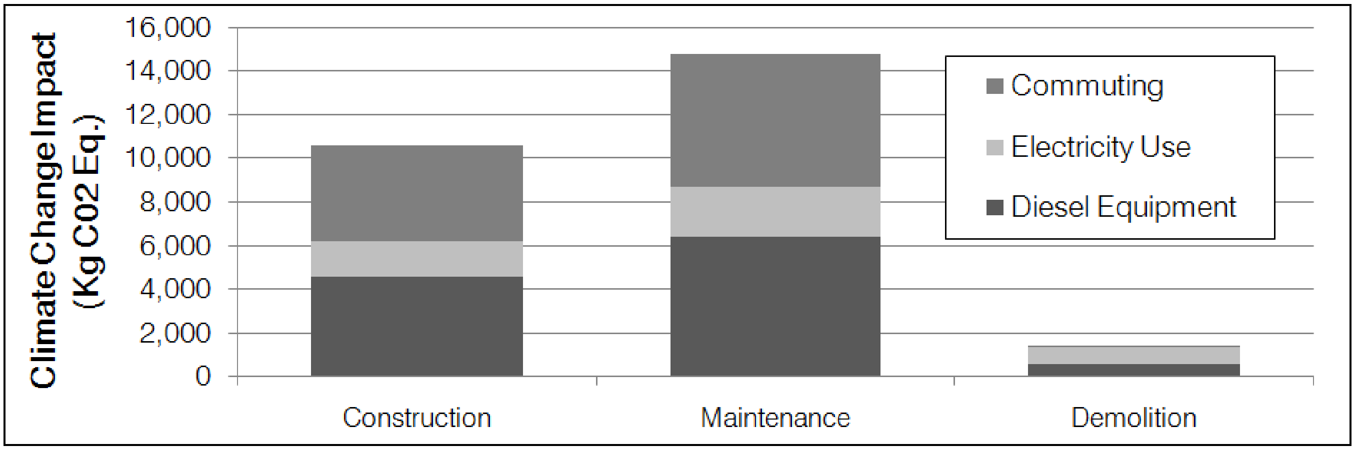


Figure 7: Climate change impact by component of the construction, maintenance and demolition stages for the standard home

Within these life cycle stages, it is the use of diesel equipment and the commuting of workers that contributes most significantly to the climate change impact, with electricity use contributing a less significant amount. As noted in Table 1, the data supporting the estimates for these stages are rather uncertain in this first phase and the magnitudes and relative proportions might change substantially if better sources of information are found. See Appendix 5 for more discussion of the modeling of these stages.

Overview of scenario results

Figure 9 shows the total climate change impact for the 25 practices that have been assessed. The values are based on the implementation of each practice in a single residence over a 70-year lifespan. Figure 10 shows the climate change benefit for each practice as a net difference from the standard scenario.

It is very apparent that because of the dominance of the use phase of the home's life cycle, it is difficult for those practices that do not impact the home's operational energy use to have a very large effect in comparison to those that do impact the use phase. Even a reduction of 50% in the other phases, which is very difficult to achieve, is roughly equivalent to only a 5% reduction in the home's energy use. The best performing scenario reduces the total climate change impact for the home by approximately 20%, with several others achieving a greater than 10% reduction. Most of the practices (16 of 25) result in a decrease of less than 3%, one of which is a net increase in the climate change impact.

The importance of electricity use in the two best performing practices should be noted (Multi-family Homes and Smaller Homes). The Standard Home is heated by natural gas and is assumed to have no cooling, so this difference in electricity is related to non-heating and cooling uses and is rather based on an expectation that inhabitants in smaller or multi-family homes would use less electricity than in the Standard Home. The REM/Rate model has been used to estimate this electricity usage for each scenario and bases its estimation by matching home characteristics to a large body of data collected from existing homes. The apparent differences in these homes might just as likely be coincidental as causal, meaning that it could be a characteristic of the inhabitant's behavior that might not necessarily change by changing the home characteristic in question. This should be kept in mind when viewing these results.

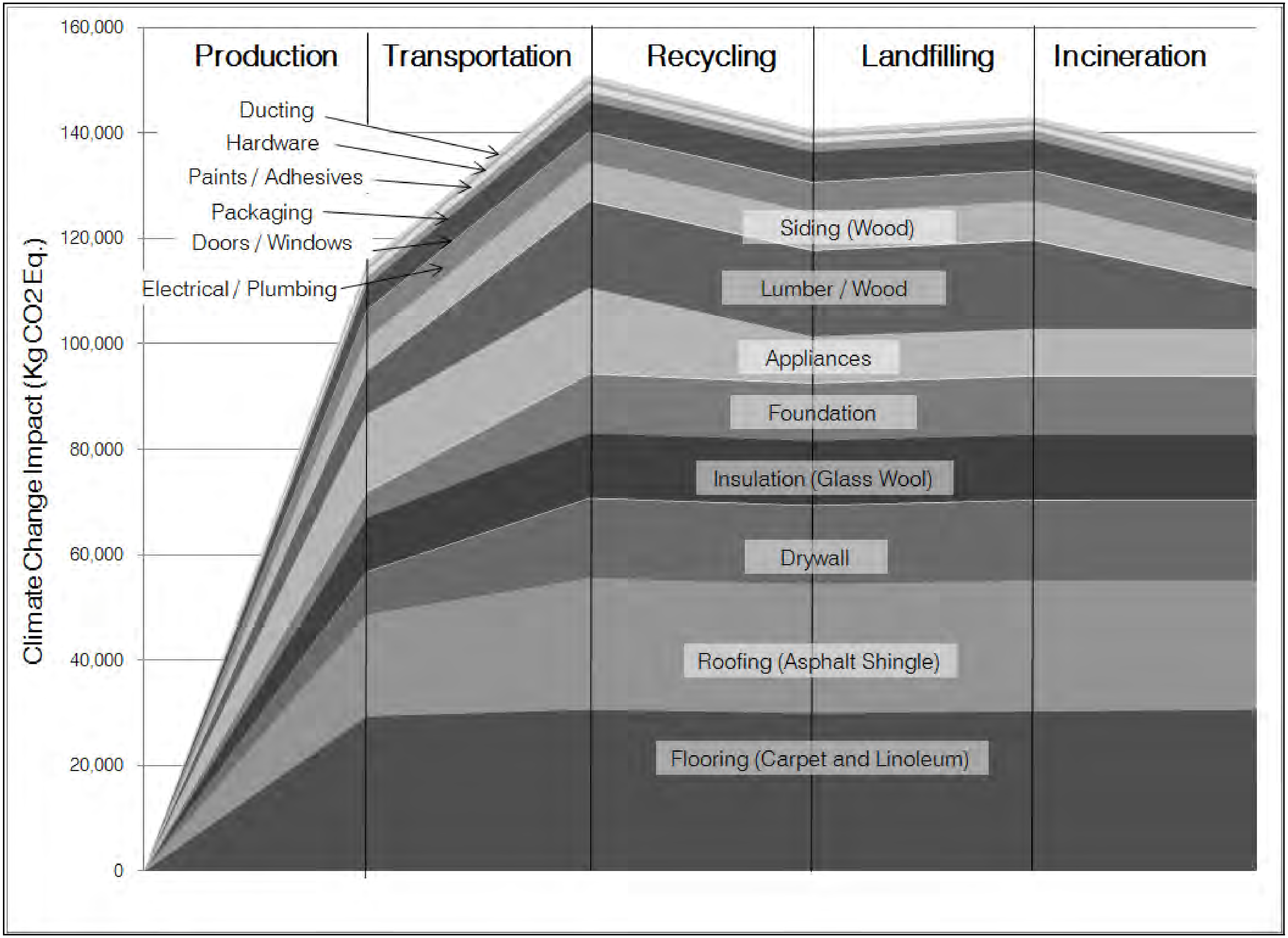


Figure 8: Climate change impacts associated with categories of materials in the standard home

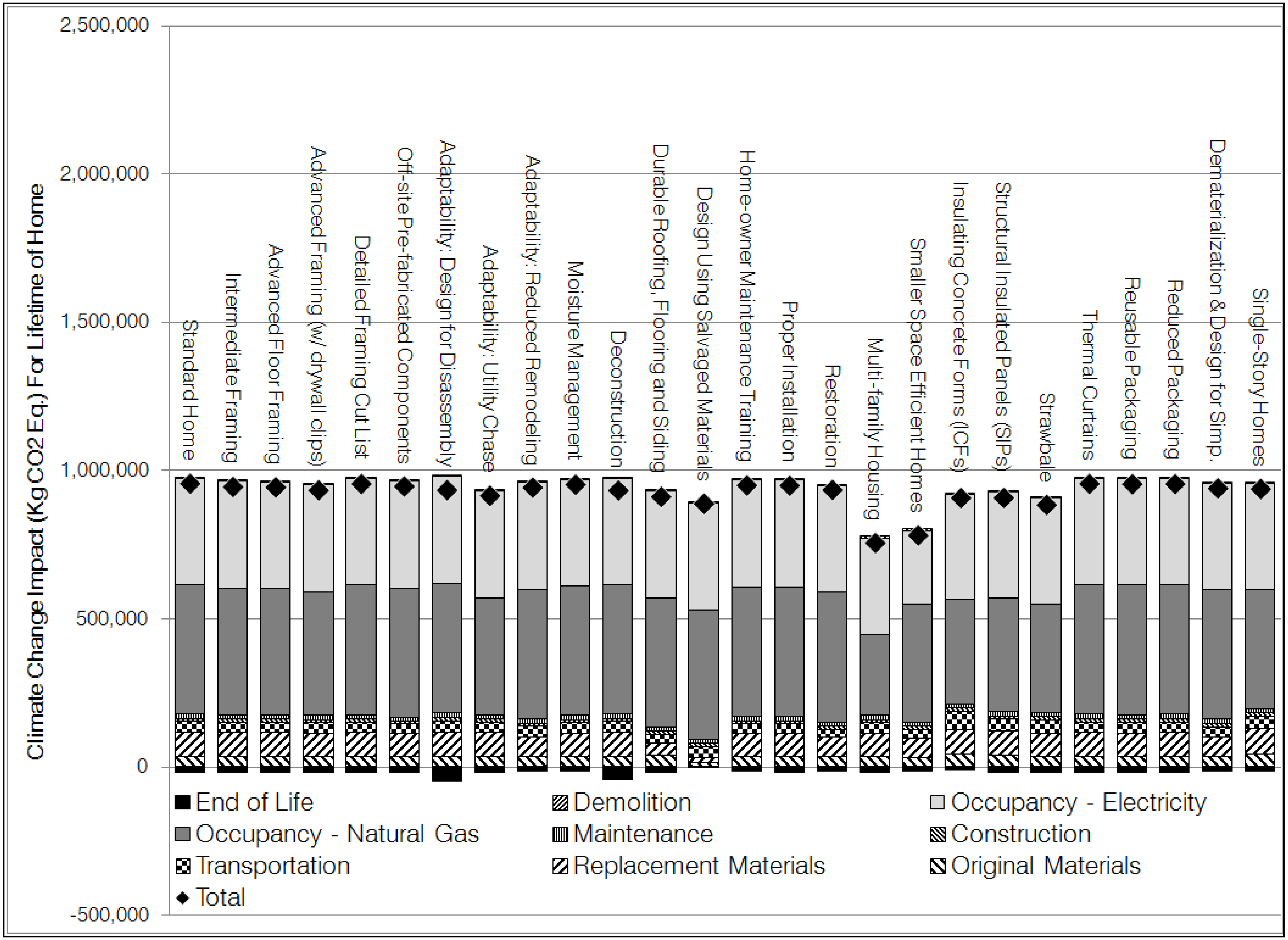


Figure 9: Total Climate change impact for the 25 practices by phase of the life cycle.

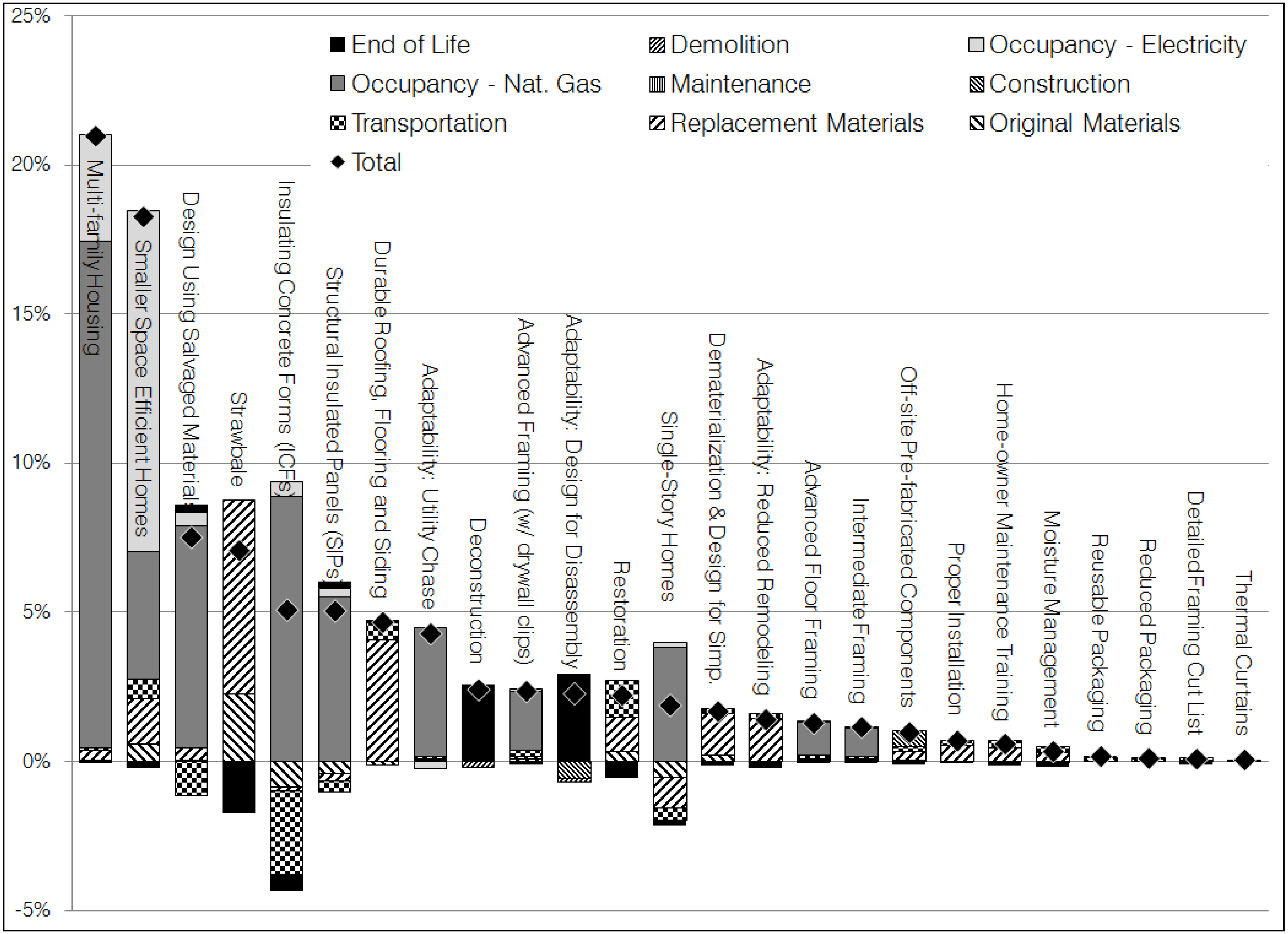


Figure 10: Net climate change benefits for each of the 25 practices, divided by life cycle stage

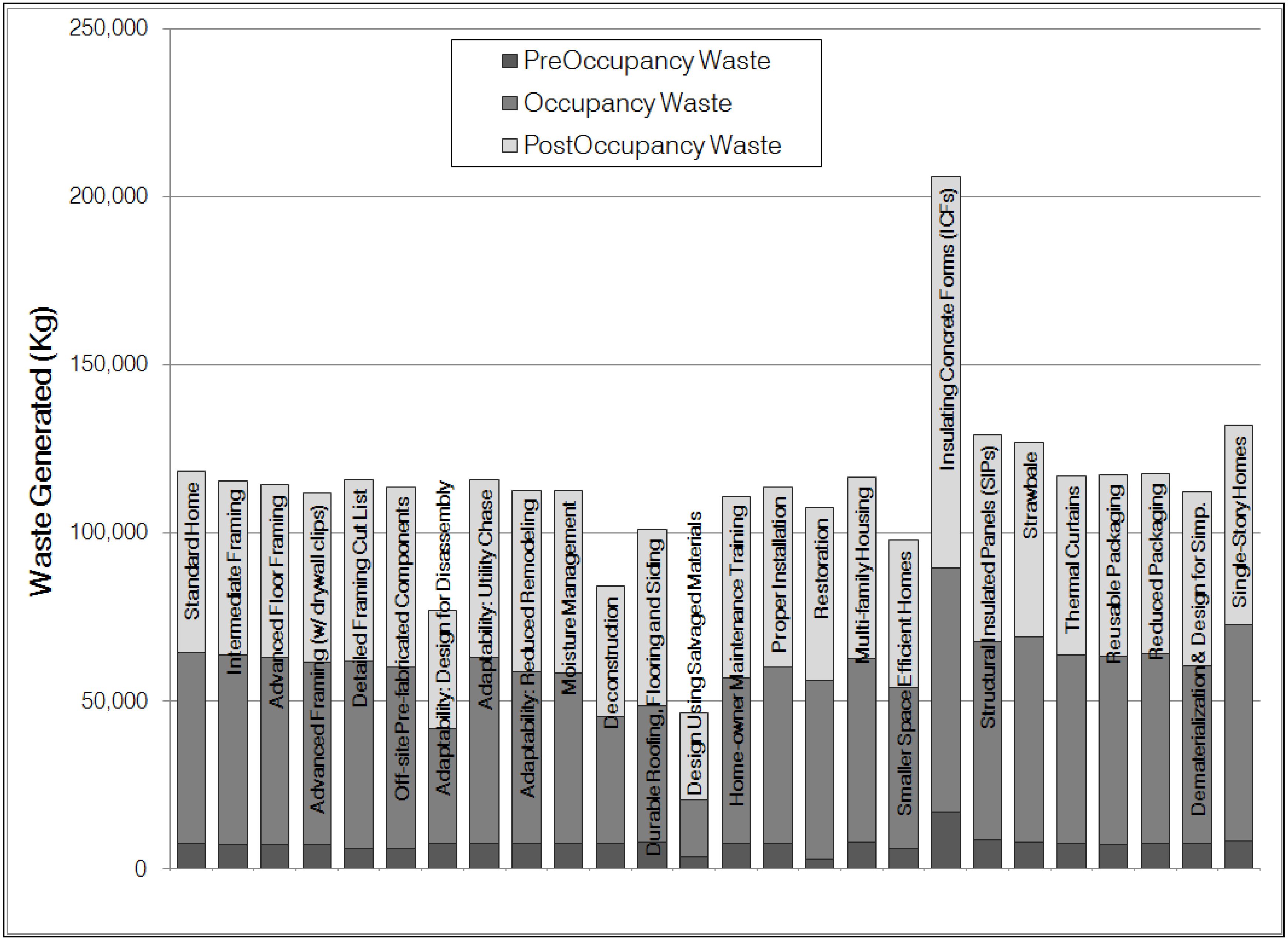


Figure 11: Waste generated under each practice, divided by preoccupancy wastes, occupancy wastes, and post-occupancy wastes

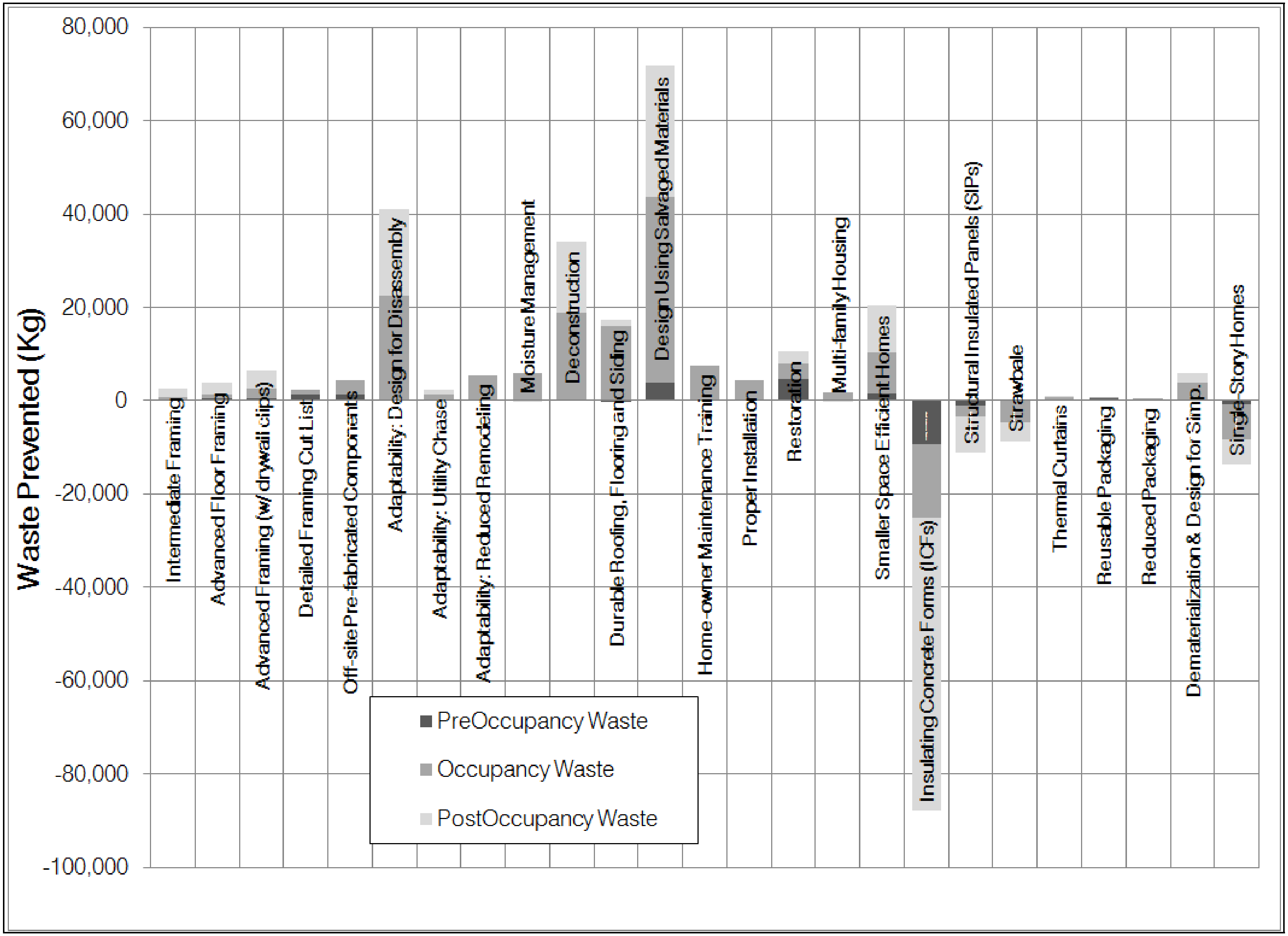


Figure 12: Waste prevention benefits for the 25 practices during preoccupancy, occupancy, and post-occupancy

As discussed above, it is often those practices with large benefits in the use phase of the home that show the greatest improvement in the climate change impact. As shown by *Design for Disassembly* and *Deconstruction*, it is possible to achieve a substantial level of improvement without a benefit in the use phase, but the benefits of such practices remain substantially lower than the best performing tier of practices.

It should be pointed out that those practices dealing with salvage and reuse of materials have each been shown as if the production of reused materials are assigned no impacts for the home in question and all impacts are given to the other home(s) in which the materials would be used. While this shows an upper bound of the benefit of advancing these practices, it is important to recognize that the results for the practices cannot be added together to show the impacts of implementing both. Appendix 6 present a sensitivity test changing the allocation of benefits for using or providing reused materials from 100% to 50%. If these practices are investigated further in Phase 2 of the project, it is expected that the boundaries will be adjusted to show the benefits of enacting such practices jointly. Assumptions about the rates of reuse of various materials are in Appendix 7.

Figure 11 shows the waste generated over the life of the home for the standard home and for each of the waste prevention practices, divided among the preoccupancy period (year 0), the occupancy period (year 1 through 70), and the post-occupancy period (year 71). Figure 12 shows the waste prevention benefit of each practice, divided among the preoccupancy period, the occupancy period, and the post-occupancy period.

As with the climate change impact, there is a wide variation in the waste prevention benefits of each practice. For purposes of comparison, the total amount of material used over the lifetime of the home is estimated by the present study to be approximately 120,000 kg. The best performing practice results in a waste prevention benefit of over 50% of the total materials used. Those dealing with the reuse or salvaging of a large percentage of materials are shown to have the most substantial impact on waste prevention. There are a handful of practices with only a very small benefit in preventing waste, while four (*ICFs*, *SIPs*, *Strawbales,* and *Single-story Homes*) are each shown as having a net negative influence on waste generation over the life of the home.

Table 5 shows the ranking (1=high) of each waste prevention practice on the metrics of climate change impact, cost savings, waste prevention, nonrenewable energy, human health impact, ecosystem quality impact, and resource depletion.

Table 5: Ranking of the waste prevention practices in key metrics (1 = high ranking, 25 = low ranking)

#	Waste Prevention Practice	Climate Change Impact	Cost Savings	Waste Prevention	Nonrenewable Energy Use	Human Health	Ecosystem Quality	Resource Depletion
1	Intermediate Framing	17	17	15	17	17	15	18
2	Advanced Floor Framing	16	16	14	15	18	16	17
3	Advanced Framing (w/ drywall clips)	10	14	8	11	12	11	12
4	Detailed Framing Cut List	24	19	17	24	19	21	23
5	Offsite Prefabricated Components	18	2	13	18	8	8	16
6	Adaptability: Design for Disassembly	11	25	2	9	5	5	7
7	Adaptability: Utility Chase	8	11	16	8	14	13	10
8	Adaptability: Reduced Remodeling	15	7	11	14	9	7	13
9	Flashing and Rainscreening	21	15	10	21	16	12	20
10	Deconstruction	9	23	3	10	4	4	9
11	Durable roofing, siding and flooring	7	3	5	3	7	23	2
12	Design Using Salvaged Materials	4	5	1	5	2	2	4
13	Homeowner Maintenance Training	20	12	7	19	11	10	19
14	Proper Installation	19	13	12	16	13	9	14
15	Restoration	12	8	6	12	6	6	11
16	Multifamily Housing	1	4	18	1	3	3	1
17	Smaller Space Efficient Homes	2	1	4	2	1	1	3
18	Insulating Concrete Forms (ICFs)	5	10	25	6	25	24	6
19	Structural Insulated Panels (SIPs)	6	24	23	7	15	17	8
20	Strawbale	3	9	22	4	23	25	5
21	Thermal Curtains	25	22	19	23	20	18	24
22	Reusable Packaging	22	20	20	20	21	19	21
23	Reduced Packaging	23	20	21	22	22	20	22
24	Dematerialization & Design for Simp.	14	6	9	13	10	14	15
25	Single-story Homes	13	18	24	25	24	22	25

Sensitivity of the Results

The sensitivity tests that have been conducted (see Appendix 6) indicate that the results are somewhat sensitive to the selection of 70 years as a lifetime for a home. While there is significant variation in the rankings of the practices for lifetime of less than about 50 years, for lifetime of 50 to 100 years, the variation is quite small.

A partial explanation of why there appears to be relatively little sensitivity at longer lifetimes is that the material replacement is also an important factor and as life of homes are lengthened, this partly (though far from fully) offsets the benefit of not constructing new homes.

Similarly, a test of the *carbon intensity* of the electrical grid shows that while there is significant variation at very low values (such as assuming most electricity was from nuclear or renewable sources), with the exception of a few practices the overall results are not highly sensitive to this parameter above 0.6 kg CO_2 eq. per MJ (roughly the carbon intensity of natural gas derived electricity). This suggests that the variation seen among locations within the United States is unlikely to influence the result of the study and the choice to use a national average electricity mix has not substantially affected the outcomes. However, if the electrical production shifted significantly to renewable over the 70-year life of the home, this change could significantly affect the relative performance of the practices.

The sensitivity test altering the allocation of benefit for using or providing reused materials shows that altering this from 100% to 50% results in a significant decrease in performance of the several practices affected, with each falling between 5 and 10 spots in the ranking of climate change benefits.

The results for rankings of the practices are highly sensitive to the environmental indicator that has been chosen, with significant variation in the rankings among the several indicators that are evaluated. This suggests that while the results of the present study might be considered reliable for estimating the climate change benefits of each of the candidate practices, the results for climate change should not be considered a proxy for overall environmental performance. It is important to consider and understand the implications of these other impact categories.

While the rankings of practices change significantly among indicators, the direction of benefit or impact of each practice is relatively consistent, with the majority of practices having all the indicators pointed to an environmental benefit. However, some practices do show net impacts rather than benefits for some indicators. Table 6 lists results for which some indicators show a net impact rather than benefit based on the Phase 1 analysis.

Table 6: Practices showing a net impact in some environmental impact categories. Percent of increase is relative to the standard home; bold values are >1%.

Practice	Indicators (Percent increase)	Comment
Detailed Framing Cut List	Ecotoxicity (0.1%), Nonrenewable Energy (0.03%)	Impacts are quite small and not substantially different than zero.
Adaptability: Utility Chase	Carcinogens (0.1%), Ecotoxicity (0.3%)	Impacts are quite small and not substantially different than zero.
Insulating Concrete Forms	Respiratory Effects (**1%**), Acidification (**2%**), Ecotoxicity (0.3%), Eutrophication (**8%**), Non-carcinogens (**1%**), Photochemical Oxidation (**7%**) Human Health (**4%**),	Increased impacts are primarily due to an increase in the transportation of materials.

	Ecosystem Quality (**3%**)	
Strawbale	Respiratory Effects (**1%**), Acidification (**2%**), Carcinogens (**1%**), Ecotoxicity (0.6%), Eutrophication (**6%**), Non-carcinogens (**2%**), Photochemical Oxidation (**6%**) Human Health (**3%**), Ecosystem Quality (**6%**)	Increased impacts are primarily due to an increase in the transportation of materials.
Thermal Curtains	Ecotoxicity (0.02%)	Impacts are quite small and not substantially different than zero.
Reusable Packaging	Respiratory Effects (0.03%), Acidification (0.1%), Carcinogens (0.01%), Ecotoxicity (0.02%), Eutrophication (0.2%), Non-carcinogens (0.06%), Ozone Depletion (0.2%), Photochemical Oxidation (0.4%) Human Health (0.2%), Ecosystem Quality (0.1%)	Differences are caused by switch of materials and/or increased shipping weights. Impacts are quite small and not substantially different than zero.
Single-story Homes	Carcinogens (0.04%), Ecotoxicity (0.09%), Eutrophication (**1%**), Non-carcinogens (**1%**), Photochemical Oxidation (0.6%) Human Health (0.4%), Ecosystem Quality (0.1%)	Increased impacts are primarily due to increased amounts of lumber for flooring and asphalt shingles for roofing, with an additional contribution from transportation.

Recommendations for Phase 2

The results for each practice are summarized in the Report Card section of the Appendix. These results have been interpreted by the project team and grades have been assigned to practices based on their performances in the environmental evaluation, in waste prevention, and in feasibility. These scores, along with recommendations regarding whether each practice should be retained for consideration in Phase 2, are shown in Table 7.

It should be noted that the recommendation to advance certain practices for further examination in the next phase is based on a prioritization of which practices show the most promise for potential benefit or show aspects that are in significant need of further investigation. It does not imply that those practices not recommended for Phase 2 would not result in tangible benefits. Neither does it imply that those practices not recommended for Phase 2 should not be pursued as important means of preventing waste generation within the state. At the time of this report, the work plan for the second phase is not yet set and so the final plan may differ than that suggested here.

Table 7: Summary of Report Card grading and recommended actions for each candidate practice

#	Practice	Environ. Grade	Waste Prev. Grade	Feasibility Grade	Recommended Action
1	Intermediate Framing	C	D	A	Advance to Phase 2 as part of wall framing comparison
2	Advanced Floor Framing	C	C	A	Advance to Phase 2 as part of wall framing comparison
3	Advanced Framing (w/ drywall clips)	C	B	A	Advance to Phase 2 as part of a "Super Waste Preventing Home" and as part of wall framing comparison
4	Detailed Framing Cut List	D	C	B	Advance to Phase 2 as Super Waste Preventing Home
5	Offsite Prefabricated Components	C	D	B	Advance to Phase 2 as part of a "Super Waste Preventing Home"
6	Adaptability: Design for Disassembly	C	A	C	Advance to Phase 2 as part of a Material Reuse analysis
7	Adaptability: Utility Chase	B	D	A	Advance to Phase 2 as Super Waste Preventing Home
8	Adaptability: Reduced Remodeling	C	B	C	Advance to Phase 2 as Super Waste Preventing Home
9	Flashing and Rainscreening	C	C	B	Advance to Phase 2 as Super Waste Preventing Home
10	Deconstruction	C	A	C	Advance to Phase 2 as part of a Material Reuse analysis
11	Durable roofing, siding and flooring	B	B	C	Advance to Phase 2
12	Design Using Salvaged Materials	C	A	C	Advance to Phase 2 as part of a Material Reuse analysis
13	Homeowner Maintenance Training	C	B	C	Do not advance to Phase 2
14	Proper Installation	C	C	C	Do not advance to Phase 2
15	Restoration	C	B	C	Advance to Phase 2, possibly combined with Disassembly and use of salvaged materials
16	Multifamily Housing	A	D	B	Advance to Phase 2
17	Smaller Space Efficient Homes	A	A	B	Advance to Phase 2
18	Insulating Concrete Forms (ICFs)	B	F	B	Advance to Phase 2 as part of wall framing comparison
19	Structural Insulated Panels (SIPs)	B	F	B	Advance to Phase 2 as part of wall framing comparison
20	Strawbale	B	F	B	Advance to Phase 2 as part of wall framing comparison
21	Thermal Curtains	D	D	A	Do not advance to Phase 2
22	Reusable Packaging	D	D	D	Do not advance to Phase 2
23	Reduced Packaging	D	D	C	Do not advance to Phase 2
24	Dematerialization & Design for Simp.	C	F	A	Advance to Phase 2 as Super Waste Preventing Home
25	Single-Story Homes	C	B	B	Advance to Phase 2

Figure 13 shows the grading received by each practice for environmental performance and how these relate to the climate change benefits estimated for each practice.

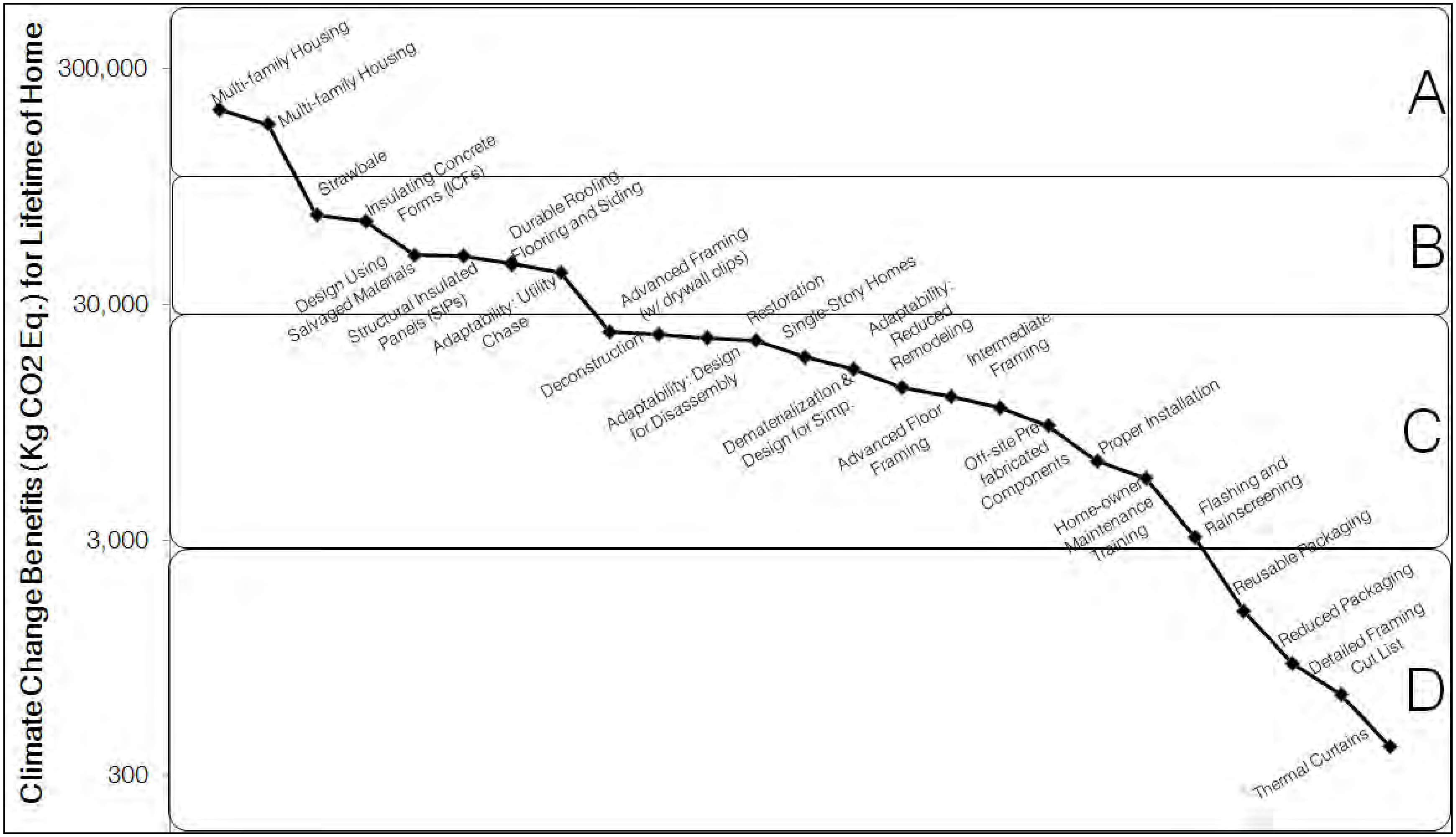


Figure 13: Climate change benefits provided per home by the candidate practices, grouped by the grade given for environmental performance (note logarithmic scale)

It is clear from Figure 13 that although there is a wide spread among the top scoring and bottom scoring practices with regard to climate change impacts (nearly three orders of magnitude), the differences between individual rankings and the categories of grades that are given are often relatively small. Given the accuracy of this screening-level assessment, while it is reasonable to assume that those receiving a grade of A are indeed better performers than those receiving a D, it is very tenuous to claim that those practices in the lower range of the B bracket are certainly better than those in the upper range of the C bracket. For example, a small change to the assumption regarding how much of the framing can be salvaged when deconstructing an older home could decrease this practice's performance to the level of those in the C category just below it.

Recommended Approach for Phase 2

The results from the Phase 1 assessment provide a basis for making decisions regarding how to structure the second phase of the assessment. The approach recommended here is to group those practices that show the greatest potential into several groups for further evaluation. This grouping makes sense for several reasons. In some cases, practices are somewhat necessarily linked. For example, the Design for Disassembly and Design Using Salvaged Materials are dependent upon each other in a supply-and-demand relationship. When considering actions for promoting either practice, it is necessary to promote both. Other practices, such as SIPs, ICFs, and strawbale, are somewhat mutually exclusive. Each individual home will very likely have only one (or none) of these wall types. While it is possible to have a system that promotes all, when considering implementation on a statewide basis in Phase 2, it is important to consider that the broad-scale implementation of some may reduce potential to implement others. Finally, some practices (for example, multistory homes and smaller homes) are similar in their nature the types of actions that might be necessary to implement them. Grouping practices will provide more clarity to the presentation of Phase 2 and provide better definition of the types of actions possible.

We recommend advancing the following topics for further examination in Phase 2:

Housing Size and Configuration

- Single / Multi-story Homes
- Smaller Space-Efficient Homes
- Multifamily Housing

This group would investigate the benefits from promoting changes to the sizes and configurations of homes. The practices to be evaluated are similar in the mode of implementation and potential limits, such as consumer acceptance and market demand. They can also be highly related. For example, multifamily homes are very likely to be multilevel structures and may often be smaller than single-family homes. Inclusion of furnishing impacts (e.g., chairs, televisions) will be important to assess the full implications of changes in home size. In addition, each of these practices will be able to be more effectively illustrated when applied at the level of the state-wide population of homes, which is anticipated to be an area of focus in Phase 2.

Material Durability

- Durable roofing, siding and flooring

The Phase 1 results suggest that a relatively small number of house components and/or materials contribute the majority of waste generation and greenhouse gas emissions. The Phase 1 analysis has looked at just a few examples of a switch to more durable materials and the preliminary findings suggest a high potential for waste prevention and other environmental benefits from making such choices. It is suggested that in Phase 2, this area be further explored by using the Phase 1 results to identify those home components that contribute most significantly to both waste generation and environmental impact and then exploring the range of materials available for each. Where adequate information is available for each alternative, an estimation of the additional up-front impacts and "pay-back" times can be made to illustrate the level of benefits that might be achieved and what added level of longevity is needed to realize them.

Wall Framing

- Structural Insulated Panels (SIPs)
- Strawbale w/ timber frame
- Insulating Concrete Forms (ICFs)
- Advanced Framing, Intermediate Framing
- Additional options (non-waste preventing): e.g., double-studded walls, staggered stud walls.

Several of the wall-framing options that were investigated showed good performance in regard to climate change and many of the other environmental impacts, even thought the Phase I assessment calls into question whether they are truly waste preventing. In addition, the Phase I assessment has not evaluated several other potential wall framing choices, such as double –studded walls and staggered-stud framing because it is not believed these would result in an overall waste prevention. However, in forming policies that might promote some wall framing practices on the grounds of waste prevention, it is also very important to understand the potential benefits of all options, so that a waste prevention policy regarding wall-framing is not selected that might diminish the total potential for achieving an environmental benefit in this area. It is suggested in Phase 2 that the current analysis of wall systems be expanded to include several additional options.

Material Salvage and Reuse

- Deconstruction
- Design for Disassembly
- Design Using Salvaged Materials
- Restoration

This group would examine practices that reduce waste by increasing the life of materials through use in multiple homes. As a group, these practices take a full view of managing materials across multiple structures over time by considering salvaging materials from existing building stock and reusing those materials in new or restored homes. It is recommended to represent these practices at the level of the total population of homes in the state so that a better view can be gained of the level of total material flows that must be managed and to reduce the importance of methodological choices regarding allocation of impacts among existing homes.

Super Waste Preventing Home

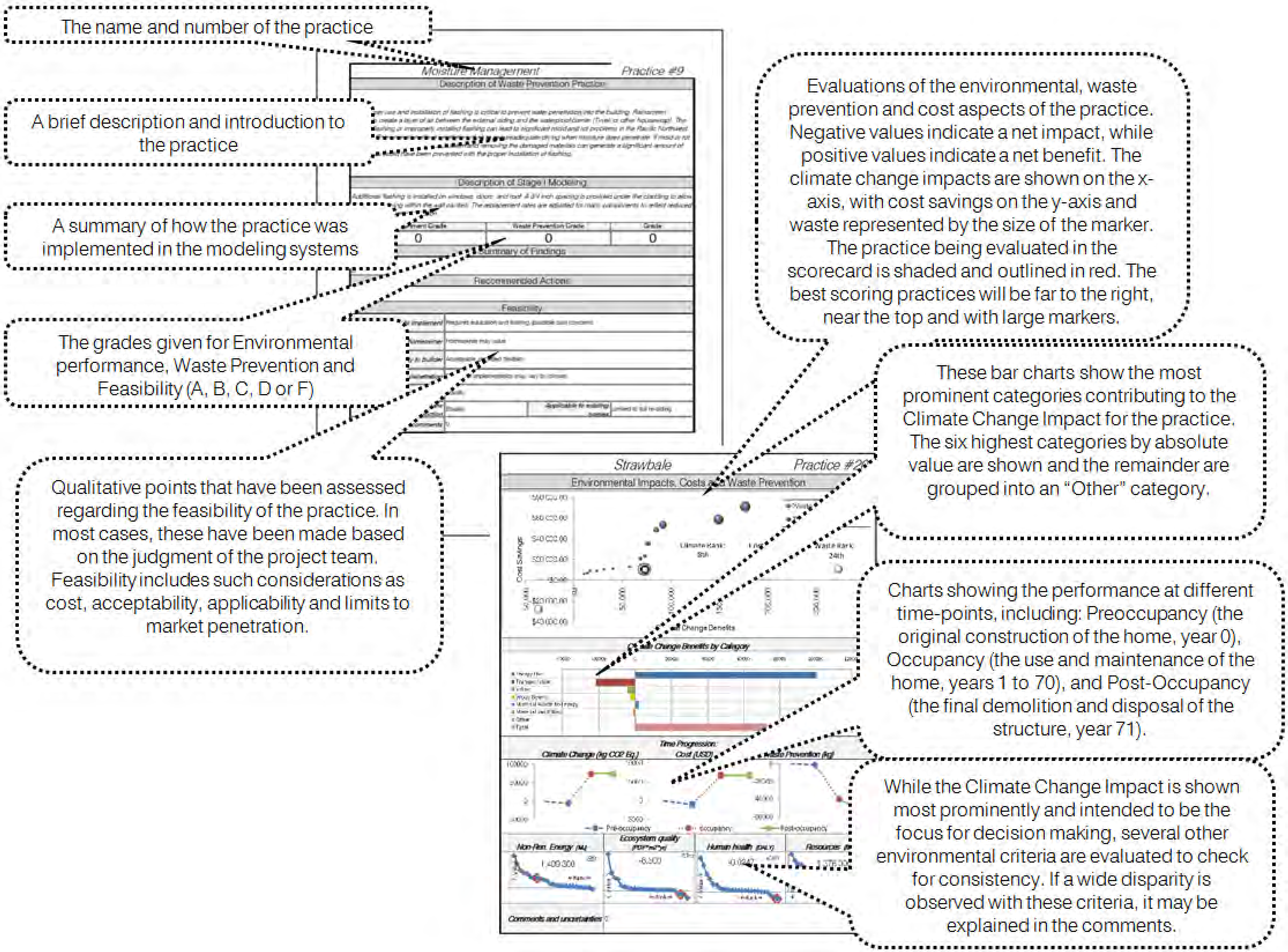
- Advanced Framing
- Adaptability: Reduced Remodeling
- Adaptability: Utility Chase
- Detailed Framing Cut List
- Design for Simplicity
- Flashing and Rainscreening
- Prefabricated Components

This group will consist of a variety of practices that affect the design of the home to show the potential for a program to promote best practices among designers and builders. It is not clear from the Phase 1 results how the carious practices presented might be combined to achieve a higher level of waste prevention than each shows on its own. It is recommended that an additional home scenario be created that represents a combination of a variety of these practices into a single home.

Material Selection Guidance

Selecting the most environmentally preferable materials is a complicated matter, with many aspects to consider and a constantly increasing range of products on the market for many components of a home. While many of these challenges are addressed under the Durable Materials category, it would also be of interest to consider the challenge more broadly to identify the important considerations and potential guidelines for selecting and promoting the use of environmentally preferable materials. A survey of available information can be compiled and important points can be illustrated based on the currently available data.

Appendix 1: Report Card Interpretation



Appendix 2: Report Cards

See attached PDF file with Report Cards

Appendix 3: Oregon Home Builders Association Modeling Methodology

The basis for the LCA baseline home is a design from a concurrent Oregon Home Builders Association study. To capitalize on the previously designed home, the partners opted to adjust the OHBA model home to better meet the assumptions of this study. The resulting baseline home scenario is intended to represent a typical, not optimal, new construction home in Oregon. There are myriad possible formats for such a typical baseline home. While it is acknowledged that alternative baseline layouts could slightly modify the results of the present study, it is not possible to quantify the magnitude of this influence on the study. It is assumed that the conclusions of the study are not sensitive to layout variations within the range of typical homes.

The Size

The first change was to enlarge the model home's square footage to the current 2,262 square feet. This size more accurately represents the median home size for new construction within the state. While adjusting the size, the group allowed the original width of the home to remain intact. The width of the model is 35', and was used to denote an important design hurtle within multistory buildings. The 2008 Oregon Residential Specialty Code details prescriptive braced wall requirements, sheer walls, for the predominant seismic zone within Oregon. In this code provision, the spacing of braced wall lines must be 35 feet on center for all homes. The provision does allow for an exemption for one- and two-story homes to extend those requirements to 50 feet. While the model could have been designed with that exception, it was important to highlight this challenge since homes may be more than two stories.

Braced wall lines are a path of sheer panels, or a continuously sheathed diaphragm that has minimal offsets to create a structure that can resist lateral and seismic loads. Structures that do not account for the required prevision will require additional materials. If the model were increased to 36 feet, to stay on module, an additional braced wall line would have been needed to comply with the sheer design requirements. If the structure required an interior braced wall line, that wall would need to be supported by a concrete foundation or doubled floor joists. If one were to use the exception and extend the spacing to 50 feet on center, the model would still be required to accommodate the required sheer amount within the allotted walls. This option may be less desirable if a building is designed with extensive glazing to accentuate a natural feature or view.

A narrower product was designed also to better meet the land use laws and city zoning requirements. When designing the model it was important to balance the dimensions to practical application. Oregon has a unique land use policy that limits sprawl. This policy leads to the predominant number of newly constructed homes to be built within the urban growth boundary. Of these homes, local zoning and economic factors often result in smaller lots and higher density.

The Shape

When designing the model it was important to keep the home simple but complex enough to simulate basic and middle scale homes. While the basic shape of the home is a rectangle, there are various indentions and bump-outs to offer visual changes. These offsets when practical continue the perimeter braced wall line. The ORSC specifies the offset of a braced wall line to 4' offsets and an 8' overall offset. It is important to note that additional material may have been needed to construct this home if those provisions were not observed during the design phase.

The Walls

The height of the model was determined by the framing stud. For this study a 92-5/8" stud was used for the wall framing. When coupled with a single sole plate and a double top plate, the overall wall height is approximately 8'-1 5/16". That is assuming the dimensional lumber's actual size is 1-9/16" X 5-9/16". When making this assumption, it was determined depending on moisture content. Dimensional lumber could vary approximately 1/8" since Oregon uses a large amount of green, non-dried lumber. It is important to note this trend may shift as the ORSC now requires the framing components to have moisture content below 19% prior to installation of interior finishes. There are various ways to achieve that benchmark, starting with a kiln dried product that may increase its market share.

For the baseline home, all interior and exterior walls have headers. As can happen in the field, similarly sized headers were used interchangeably within the home. This often happens with little or no regard to sizing to meet the design needs. Due to business practices, interior nonbearing headers are often removed. In this case, the group felt it was important to rely on what is permitted within the code language since builders could still include interior nonbearing headers.

The Floor System

For the baseline model, a traditional post and beam system was used for the main level floor system. The group believed that this practice still held a large market share. While the market may be moving to dimensional or engineered lumber, the group felt that the post and beam should be used in the baseline with dimensional and engineered joists modeled in some of the methods.

An engineered sheeting product was chosen for the subflooring in the home. While there are homes being built with boards, the majority of homes use plywood sheeting.

The Process

Once the design criteria were established, the original OHBA home was redesigned using computer aided drafting and design software. In the software, 2D and 3D models of the baseline home were created. With these models, material takeoffs were extrapolated for the baseline home. Along with materials, wall details were exported to spreadsheet software to be incorporated into the energy modeling. This data included the wall lengths, heights, wall cavity volume, window and door surface area, framing volume, and the relative percentages of each component to the overall wall.

When looking at each individual measure, various resources were used. These resources included product installation and design material, building codes, industry standards, and best practices. When available, existing research was used as supportive material. It is important to note that material mass, spans, and characteristic can vary from that of this study depending on manufacture, species, moisture content, and installation technique.

Appendix 4: REM/RATE Energy Modeling Methodology

Operational energy use was modeled using the REM/Rate software tool. REM/Rate is published by Architectural Energy Corporation of Boulder, Colorado, and complies with Residential Energy Services Network (RESNET) protocols for modeling home energy ratings. It is used nationally to qualify homes for the ENERGY STAR® home program. Energy modeling seeks to predict energy use by calculating heat loss and gain through each building component, such as wall, floor, and roof assemblies, as well as windows. REM/Rate also incorporates heating and cooling system types and efficiencies along with lights and appliance use.

Predictive energy models will always be inaccurate to some degree. The biggest factor is occupant behavior, which includes temperature settings, hot water consumption, and usage of lights and appliance.

A recent study of three modeling methodologies titled Energy Performance Score 2008 Pilot compared three modeling methodologies. While REM/Rate was not the most accurate overall, its accuracy in predicting energy use for recently-constructed homes was comparable to the other two methodologies.

Since the same model is used across all scenarios, any inaccuracies are consistent and should therefore not affect the relative ranking of the practices.

For this study, the OHBA model house was used as a baseline. The house was modeled as if built to the 2008 Oregon Residential Specialty Code with the following characteristics:

- Weather: Portland, Oregon
- Conditioned floor area: 2,262 sq. ft.
- Conditioned building volume: 20,358 cu. ft.
- Bedrooms: 3
- Bathrooms: 2
- Foundation: vented crawlspace
- Framed floors: R30

- Walls: R21, framing factor 26%
- Windows: typical double-glazed, low-e, vinyl frame, U-0.35, 374 square feet windows area. Windows oriented to minimize solar gain.
- Doors: 2.25-inch solid wood, R2.8
- Ceiling: R38
- Heating: 90% efficient gas furnace
- Duct leakage: RESNET/HERS default, all duct leakage outside the thermal envelope
- Water heating: 58% efficient gas storage tank
- Building Air Leakage: 6.5 ACH at 50 Pascals

Energy use for lights and appliances was determined by REM/Rate based on its database of information on the actual energy use by a wide variety of homes. The program matches each scenario to the information in its database to determine the most likely energy use for that scenario. It should be noted that differences in energy use are based on associations or correlations and not necessarily causal relationships.

Many of the LCA scenarios evaluated in Phase 1 gained significant benefits from improvements in operational energy. These scenarios were modeled by making specific changes to the base case characteristics. Other scenarios did not have an energy use impact, so modeling was not performed.

1 Intermediate Framing

While the base case home was designed to represent a traditional framing approach, many builders already incorporate framing practices that reduce framing members not strictly required for structural purposes. Much of this additional wood framing serves to support interior gypsum board, sometimes called *nailers*. Phase 1 evaluated several of these steps independently. Intermediate framing eliminates many nailers in exterior corners and reorients others to provide proper support for gypsum board. This eliminates un-insulated areas of exterior walls and reduces the amount of lumber used. In the energy model, the framing factor is the percentage of the wall's surface area occupied by lumber. Wood has an insulating value of only about R1 per inch, while fiberglass insulation is typically rated at R3.5 per inch. Framing is called a *thermal bridge* because the lower insulating value of lumber allows greater heat loss through the assembly. Framing is a very sensitive factor in the overall heat loss of the wall assembly. In Phase 1, the base case house was designed with a framing factor of 26%, while the intermediate scenario reduced this to 23%. It is noted that framing factors vary widely by housing design. In Phase 1, the design identified the location of each framing member to support the calculation of the framing factor.

2 I-joist Floor

Full dimensional lumber used in floor framing is 1.5" wide by 9.25" deep, and spaced 16" on-center. In the I-joist floor system, dimensional 2x material is replaced with wood I-joists, which use less lumber and allow spacing to be increased to 24". Although it is possible to achieve greater spacing with I-joists (e.g., 36" on center), the current home design was such that this greater spacing might compromise structural integrity.

3 Advanced Framing

The term *advanced framing* refers to a collection of practices that eliminate structurally unnecessary wood framing from the building. The concept was originally developed for the National Association of Home Builders in the 1970s when it was called Optimum Value Engineering. For the purposes of Phase 1, advanced framing has been restricted to practices that builders would be able to apply to almost any building design. The starting point is the Intermediate Framing practices in scenario 1a, plus the I-joist floors from scenario 1b. The principal addition is increasing stud spacing to 24" on-center, which reduces the framing factor to 18%.

17 Small House

The small house scenario is redesigned from the base case home to reduce overall floor area while retaining all the same functions. The conditioned floor area drops to 1,633 square feet. There is also a corresponding decline in window area from 374 square feet (16.5% window to floor area) in the base case to 301 square feet (18.4% window to floor area) in the small house. The framing factor also drops slightly from the base case to 25%.

19 Structural Insulated Panels

Many of the limitations of wood-frame construction are overcome with structural insulated panels (SIPs). Roof, wall, and floor structures are assembled in a factory into a sandwich of oriented strand board (OSB) surfaces and a core of rigid foam insulation. In Phase 1, this core material is expanded polystyrene (EPS), generally considered to be one of the foam plastics with lower overall environmental impact. The insulating value of each panel is determined by the thickness of the EPS core. One clear advantage of SIPs is the radical reduction or elimination of wood framing and the associated thermal bridges. For this scenario, insulation values were increased a modest amount to reflect this benefit of the technology. Wall panels are specified at 6.5" overall thickness for an insulating value of R-23. Roof panels are 12.25" for R-46. Using roof panels increases the conditioned volume by 5,555 cu. ft. and the ceiling surface by 294 square feet. Air leakage is reduced to 5.0 air changes per hour (ACH) @50 Pascals. This value is 23% lower than the base case. While many SIPs houses obtain even more impressive air leakage reductions, such savings result from careful installation and attention to detail that is not inherent in the use of this material. In other words, it is possible to build a leaky SIPs house, so the team selected a mid-level air leakage rate. Another factor that might also have been included was the use of space created by moving the thermal boundary from the ceiling to the roof. Small attic and knee wall spaces are ideal for locating heating ducts. In order to show a clear result of the SIPs alone, the duct locations were not changed from the base case. These two factors slightly increase heat loss relative to what could be envisioned. However, the overall performance of SIPS still exceeds the base case by a considerable margin.

18 Insulating Concrete Forms

Another alternative to wood-frame construction is a system of stay-in-place concrete forms that also provide insulation. Called insulating concrete forms (ICFs), this product is most commonly used for walls, but systems are available to build floors and roofs. Phase 1 focuses on ICF wall construction. ICF units can take several forms but are generally formed blocks or sheets held together at a set distance by ties. This creates two layers of insulation and a void into which concrete is placed. For the purposes of this assessment, the ICF is assumed to have 2.5" of foam insulation on each side for an assembly insulating value of 24. As with SIPs, ICF does not have thermal bridges so this insulation is continuous across the entire wall surface. The ceiling and floor construction has not been changed from the base case. Air leakage has been set at 5.0 ACH@50 Pa using the same rationale as was used with SIPs.

Appendix 5: LCA Modeling Methodology

Scope of the Study and Stages of the Life Cycle

The focus of the Phase 1 LCA model has been to allow a high level of flexibility for rapidly running scenarios and sensitivity tests. The LCA has been configured to be able to fully utilize the amount of high-quality information being provided by the OHBA and REM/Rate models. The model is based on a characterization of a standard Oregon single-family home, which is assumed to have a lifetime of 70 years. Refer to Figure 4 for a listing of the life cycle stages and the aspects included in each.

The standard home characteristics have been selected by the project team based on the need to balance a number of important criteria, the most prominent of which are a desire to represent the most common characteristics and practices presently employed in new-construction homes within the state and a need to be able to use the standard as a backdrop for evaluating the waste prevention practices that have been identified.

Although the scope of the study is broad and the level of detail rather high for a screening-level study, many simplifications have been made in scope and detail where it has been felt that they could be made without greatly sacrificing the certainty of the outcomes. For example, some minor structural components (weighing much less than a percent) may be excluded. However, a strict cutoff threshold has not been applied, as it was felt more appropriate to include any materials for which reasonable estimates could be made on the amount of material used and supporting LCA data of reasonable quality could be obtained.

Aspects of the use phase not anticipated to be significant drivers of the results (i.e., not affected by the waste prevention practices) have also been excluded. For example, it is not known whether any of the waste prevention practices would significantly affect the amount of water used by the home's inhabitants and therefore municipal water use during occupancy has been excluded. For the current screening-level assessment, only the heating fuel and electricity use of the home were considered. The REM/Rate model allows for the estimation of home electricity use and how it would be expected to vary depending on housing characteristics. Other aspects, including the use of water, transportation, and personal possessions of the occupants, have not been considered. There are many aspects in which the line between a component of the home and a possession of the inhabitants is not clear. In the present case, an attempt has been made to include those items that would typically be included with a home when it is sold or rented, but exclude any other furnishings or other property of the homeowners. Therefore, major appliances (e.g., refrigerator, furnace) and lighting fixtures were included, while chairs, wall hangings and minor appliances (e.g., toasters, televisions) were excluded. In the second phase of the study, efforts will be made to more fully characterize other possessions or activities of the inhabitants, as some practices, such as smaller homes, could impact these other characteristics.

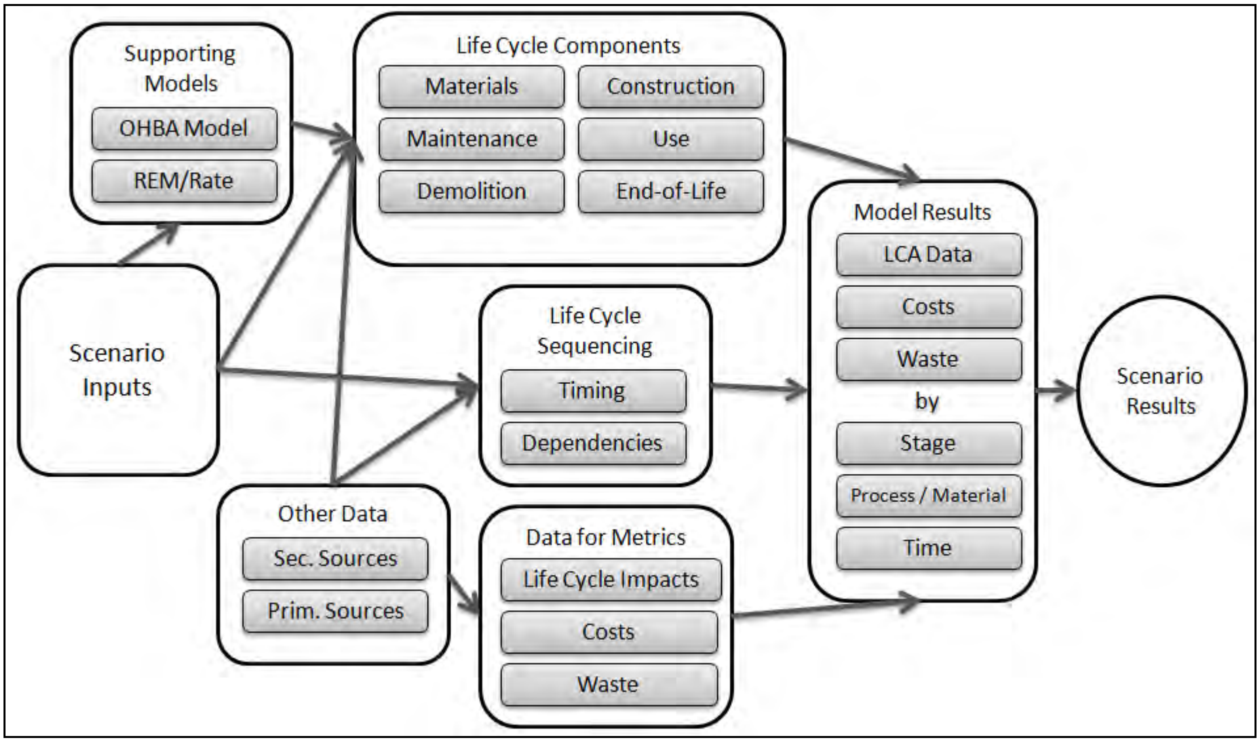
Information Structure

For each of the life cycle stages listed above, the processes and materials that are involved have been quantified and matched with data that describes their costs, amount of waste generated, and environmental impact metrics. In addition, each process or material identified has been classified with regard to the timing at which it occurs during the life cycle of the home (see Appendix 8).

This information has been totaled for each component of the building over its entire life cycle to produce an estimate of the total environmental impacts, costs, and wastes generated during the life cycle of the home. These metrics have been sub-classified by the stage of the life cycle, the component of the home and the timing of their occurrences.

Each of the waste prevention measures evaluated has been characterized based on a broad set of variables. Following the creation of the model for the standard scenario, variations have been developed for each of the scenarios to be tested. These scenarios include any additions, deletions, or modifications to the list of processes and materials, as well as any changes to the timing of the occurrence of each. In many cases, the OHBA model home and REM/RATE have been used to process aspects of each scenario and the output of these models is implemented in the life cycle model. To ensure that the waste prevention measures are able to be adequately modeled, the scenario definition and model creation have taken place together through an iterative exchange and review of information among the project team.

The information flow for the Phase 1 LCA calculations is shown in the following figure:



Calculations and Information Sources

Material and process quantities

The amount of each material being used each year has been determined based on an estimate of the amount used in the home, a *waste factor* (which defines an additional amount that is brought to the construction site and discarded, but never incorporated in the home) and a replacement schedule (which is determined based on a typical annual replacement rate). All materials are assumed to be sent to end-of-life at the end of the 70-year life of the home.

The materials in the home have been determined by a detailed home materials list provided by the OHBA and based on a detailed CAD-based model of the standard home. Additional materials have been added to this list to represent some of the finishing elements, such as appliances and lighting fixtures. The full materials list is included in Appendix 9.

Packaging has been assumed to total 1,200 pounds for the life of the home. This is consistent with the estimates of several studies of waste content from construction sites. It was assumed that the packaging weight is evenly divided among corrugated cardboard, flexible plastic packaging (LDPE), and rigid plastic packaging (polystyrene).

Waste Factors

The waste factors were set to 15%, 5%, or 0% for all materials in the standard scenario. Zero percent was used for those materials in which there was no reason to expect a certain percent was wasted (e.g., furnaces). Five percent was used for those materials for which it can reasonably be expected that most additional materials will be reused at another building site (e.g., roofing shingles). Fifteen percent was used for those materials that were not expected to be reused (e.g., lumber).

For the scenarios of Detailed Cut List and Prefabricated Components, these estimates were revised downward for some materials as show in Appendix 7.

For the reuse of salvaged materials, a waste factor was applied identical to that used for the equivalent amount of non-salvaged material. However, as with salvaged materials that were not wasted (i.e., that were used in the home), these wasted salvaged materials were not classified as waste.

Replacement Schedules and Rates

Each material in the home is assumed to be replaced over time based on a replacement rate (which can be equal to zero, indicating no replacement). This is implemented as an annual average rate of replacement and is differentiated based on types of materials and components of the home. For example, lumber used in flooring is specified with a different rate than lumber used in walls, which has a different rate than the gypsum plasterboard used in walls.

The replacement is represented as happening on an even basis over the life of the home. For example, if the home will receive three replacement roofs over its lifetime (e.g., at 20, 40, and 60 years), it is assumed to receive (3/70=) 4.29% of a new roof each year. Calculating the replacements in this manner leads to some absurdities when considering a single home (none of which would actually have 4.29% of a roof replaced each year for 70 years), but is equivalent to a more time-specific approach over the life cycle and offers a substantial benefit by avoiding the large gradations that occur in assuming an all-or-none replacement. For example, if assuming a new roof every 20 years, after extending the life to 24 years (at which point 2 replacements would suffice rather than 3) a further lengthening of roof life would not be evident until it was lengthened to 35 years (at which point only one replacement occurs) in the all-or-none approach, differences of fractions of a percent can be reflected in the continuous approach. This difference is important in assessing some of the waste prevention scenarios, which will modify these replacement rates. Further, it is reasonable over a population of homes to assume a gradual replacement rate.

The rate of replacement has been divided into 5 primary causes, which reflect various reasons a homeowner might replace components and which might be impacted by the waste prevention scenarios under consideration. These include replacement due to deterioration (the item wears out), replacement due to water damage from outside, replacement due to water damage from inside, replacement due to improper installation, and replacement due to owner’s preference (remodeling for no other reason). The total replacement rate is represented as a sum of individual rates for each of these causes.

Data to support the quantification of each of these replacement causes has been assembled primarily from the American Home Survey data for the Portland metropolitan area. In interpreting the data, many assumptions had to be made. The replacement rates that have been used and the supporting rationale are given in Appendix Table 8.

Transportation

Material transportation is characterized by the amount of weight and distance traveled by each item. For all transportation, it is assumed that the shipments are limited by weight and that the impact can be most accurately quantified based on the product of distance and weight (e.g., ton-kilometers). Weights for each material are calculated based on manufacturer's specified shipping weights, or calculations of material size and density. All materials are assumed to travel 1,500 km (932 miles) from the site of production to the building site, with 72 km (45 miles) occurring at end-of-life to move the materials to their eventual disposal or processing location. While the 1,500 km and 500 km numbers are assumptions, the 72 km was provided by Oregon DEQ staff as representing the average distance materials are hauled to landfill in the state. It has been assumed that equivalent transportation takes place for other end-of-life fates (e.g., recycling or waste-to-energy).

All transportation occurring upstream of the manufacturing facility is included within the scope of materials production and is not calculated explicitly in this study.

Each scenario's transportation weight is modified based on the extent to which the list of materials is modified. No scenarios change the assumed transportation distances.

Construction, Maintenance, and Demolition

The construction, maintenance, and demolition activities have been estimated by the judgment of the project team and have not been verified by field-collected data. The assumed amounts are listed in the following table:

Stage	Process	Amount
Construction	Diesel Equipment Operation	100 equipment hours
	Electricity	2,000 kilowatt hours
	Worker Commuting	300 worker days at 50 km per worker-day
Maintenance	Diesel Equipment Operation	140 equipment hours (2 per year)
	Electricity	2,800 kilowatt hours (40 per year)
	Worker Commuting	420 worker days (6 per year) at 50 km per worker day
Demolition	Diesel Equipment Operation	12 equipment hours
	Electricity	1,000 kilowatt hours
	Worker Commuting	4 worker days at 50 km per worker day

Material End-of-Life

Each material used in the home is sent to a combination of reuse, recycling, landfill, or incineration facilities (with partial energy recovery). It is assumed that no reuse occurs in the standard scenario and only in the Deconstruction and Adaptability/Disassembly scenarios. Within those scenarios, material reuse is based on estimates provided by experts in the field of building deconstruction. Those scenarios are intended to represent upper-level limits of what can be salvaged. For the remaining materials that are not reused, they are assigned to fates of recycling, landfilling, or incineration based on information provided by Oregon DEQ and based upon the State Material Recovery Survey and Waste Composition Study for 2005.

For materials that enter the general municipal waste disposal stream (meaning they are neither reused, recycled, or specifically diverted for energy recovery), it is assumed that 93% are sent to landfills, 6% are incinerated with energy recovery, and 1% are incinerated without energy recovery. The end-of-life fates of materials by material class are shown in Appendix 13.

Costs

Each material or process occurring during the life cycle of a home is assigned a cost. *The cost assessment made in this first phase of the assessment is very preliminary.* No efforts have been made to adjust for future inflation or to correct future prices with a discounting rate. It is therefore assumed that all costs over the 70-year life of a home occur in 2009 dollars and at a consistent price.

Cost data are taken from a wide variety of sources and assumptions. The assumed costs and references are listed in Appendix Table 12. In cases where no reference could be found, an approximation was made based on similar materials.

Life Cycle Inventory Data Sources

The sources of data that were used to represent the production of materials or provision of energy or services in this study are shown in Appendix Table 10, along with the impacts of each quantity of materials rolled-up to the impact level. For example, the total global warming potential is shown rather than the emissions of each greenhouse gas.

Data has been primarily drawn from the ecoinvent database (v2.01; ecoinvent, 2007). This database has been chosen because it provides the most complete and consistent set of data of this type available. In total, the database includes more than 4,000 sets of data regarding different materials or processes, including a large number specific to the building industry. In addition, it contains a relatively robust and consistent treatment of the end-of-life management of various materials.

Although much of the data in ecoinvent represents European conditions, it is expected that as a whole, the advantages of this database in other regards will outweigh this disadvantage for its use here. In a few select cases, either where corresponding data was not available in ecoinvent or where there was a different compelling reason, LCI data has been drawn from some other sources. This includes the use of some data from the U.S. LCI database (NREL, 2008) and the BEES database (NIST, 2008). Attempts have been made to select data that most closely represents the geography of the present study as possible. For example, the data selected from the U.S. LCI database is primarily related to wood production in the Pacific Northwest. Electrical use reflects the average production for the U.S. grid and a scenario has been conducted using a variety of carbon emission intensities for electrical production, including one similar to the production of the Western U.S. states. Additional updates of data are anticipated for Phase 2.

Impact Assessment Methods

The conclusions of the study have primarily been based on an assessment of the impacts the home has in contributing to global climate change. Just as there is a danger in basing environmental impacts on a surrogate measure like waste generation, there is also a danger in basing decisions on only one category of environmental impact. It is quite possible that actions that will achieve improvements in this one category could have important detriments in other categories. The group has therefore evaluated several additional impact assessment metrics that represent other types of impact categories.

The IMPACT 2002+ methodology has an advantage in that it uses scientific principles to evaluate a wide variety of human health and ecosystem impacts into single metrics for these categories. For simplicity, the results for these metrics, along with the results for resource depletion and nonrenewable energy use from that methodology, have been included in the scorecard. Because it has greater geographic relevance for the United States (IMPACT 2002+ is configured for Europe), the U.S. EPA's Tool for the Reduction and Assessment of Chemical Impacts (TRACI) has also been used and the results are shown in the sensitivity tests.

It is important to point out that for the impact categories relating to human health, only the health impacts occurring from the release of substances into the wider environment and the exposure to humans from the environment (*not* the direct exposure to those inhabiting the home through indoor air or dust) are considered in this LCA. To make an assessment of the home's inhabitants within an LCA is beyond the current capabilities of the science due to a lack of information on the release of chemicals from building materials and the lack of an established method for incorporating exposures within the indoor environment into a life cycle impact assessment. However, recent developments are moving toward making this feasible (Hellweg, 2009).

No attempt has been made to sum or combine the results from disparate impact categories. While the study results are calculated based on temporal profiles of the sequencing of impacts, no weighting has been given in the results to impact based on the time at which they occur.

Descriptions of each of the impact metrics that have been used here are provided below:

<u>Climate Change</u> is represented based on the International Panel on Climate Change's 100-year weightings of the global warming potential of various substances (IPCC, 2007). Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in grams of CO_2 equivalents. Because the uptake and emission of CO_2 from biological sources can often lead to misinterpretations of results, it is not unusual to omit this biogenic CO_2 from consideration when evaluating global warming potentials. Here, we have followed the recommendation of the PAS 2050 product carbon footprinting guidance in not considering either the uptake or emission of CO_2 from biological systems and correcting biogenic emissions of other gasses accordingly by subtracting the equivalent value for CO_2 based on the carbon content of the gas (BSI, 2008).

Nonrenewable Primary Energy Use accounts for the consumption of fossil and nuclear resources but excludes sources of renewable energy at all stages of the life cycle and in all upstream processes. This metric is expressed here in megajoules. It is assessed here based on the IMPACT2002+ methodology (Jolliet et al., 2003).

Human Health impact can be caused by the release of substances that affect humans through acute toxicity, cancer-based toxicity, respiratory effects, increases in UV radiation, and other causes. An evaluation of the overall impact of a system on human health has been made following the human health end-point in the IMPACT 2002+ methodology (Jolliet et al., 2003), in which substances are weighted based on their abilities to cause each of a variety of damages to human health. These impacts are measured in units of disability-adjusted life years (DALYs), which combine estimations of morbidity and mortality from a variety of causes.

Ecosystem Quality can be impaired by the release of substances that cause acidification, eutrophication, toxicity to wildlife, land occupation, and a variety of other types of impact. An evaluation of the overall impact of a system on ecosystem quality has been made following the Ecosystem Quality end-point IMPACT 2002+ methodology (Jolliet et al., 2003), in which substances are weighted based on their ability to cause each of a variety of damages to wildlife species. These impacts are measured in units of potentially disappearing fractions (PDFs), which relate to the likelihood of species loss.

Resource Depletion is caused when nonrenewable resources are used or when renewable resources are used at a rate greater than they can be renewed. Various materials can be weighted more heavily based on their abundance and difficulty to obtain. An evaluation of the overall impact of a system on resource depletion has been made following the resources end-point in the IMPACT 2002+ methodology (Jolliet et al., 2003), which combines nonrenewable energy use with an estimate of the increased amount of energy that will be required to obtain an additional incremental amount of that substance from the earth based on the Ecoindicator 99 method. These impacts are measured in megajoules (MJ).

Carcinogens are chemicals believed to contribute to the incidence of human cancers through release into the environment and subsequent human exposure. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of benzene equivalents.

Non-carcinogens are chemicals whose release to the environment is believed to contribute to the incidence of human morbidity or mortality through chronic health effects other than cancer. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of toluene equivalents.

Respiratory effects are the result of releasing chemicals to the environment that cause acute harm to human respiratory systems and that may contribute to morbidity or mortality through these pathways. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of $PM_{2.5}$ equivalents.

Acidification is the lowering of pH in natural water bodies through the release of acidifying substances to air, land, or water. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in moles of H^+ equivalents.

Ecotoxicity is the harm to wildlife, including all types of flora and fauna, through toxic effects of environmental pollution. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of 2, 4-D equivalents.

Eutrophication is the lowering of dissolved oxygen in natural water bodies through an increase in the amount of nutrients (such as phosphorous and nitrogen) in the water body, promoting excessive growth of microorganisms. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of nitrogen equivalents.

Ozone depletion is the decrease in ozone in the stratosphere, where it serves to block UV rays from penetrating the atmosphere. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of CFC-11 equivalents.

Photochemical oxidation is the creation of oxidizing compounds in the troposphere from environmental pollution (usually the release of nitrogen oxides and volatile organic compounds), also commonly called smog. The weightings applied here are those from the TRACI methodology (Bare, 2003). These impacts are measured in kilograms of NO_x equivalents.

Electricity Production

Electricity is an important factor in the overall impact of the home throughout its life cycle, primarily due to the use of electricity by the home's inhabitants. In the standard home, natural gas is the assumed heating fuel, but the electrical use of the home nevertheless contributes approximately 40% of the total climate change impact across the life cycle. The choice of how to represent that electrical production is therefore important. Here, the group has chosen as the default assumption to use the average production of electricity going into the U.S. national grid (with a carbon intensity of 0.86 kg CO_2 equivalents per kWh, based on the U.S. grid mix data from the ecoinvent database). Although it is possible to more specifically identify the production within a given state or region, this can lead to a false sense of greater precision because of the interconnectedness of the electrical system. For example, there is no reason to believe the consumption of one kWh less or more of electricity in Oregon would result in emissions that are based on the production within that state.

To test the importance of the choice of the U.S. average grid mix, a series of sensitivity tests have been conducted on varying carbon intensities and are presented below. These span the range of those that would be expected for renewable energy sources (<0.1 kg CO_2 eq. per kWh), the Western states' grid (~0.6) and 100% coal-derived electricity (~1.2). Because it is nonrenewable energies that are most often fluctuated to meet changes in demand, it is often interesting to consider these technologies, such as coal, when considering the impacts of making a change in demand. Future changes in technologies are not considered explicitly in this study.

It is important to point out that the above discussion and the scenarios shown apply only to energy that is directly used by the home or in the home's construction, maintenance, and demolition. It does not apply to the production of materials or to electricity used further in the supply chains of any of the materials and processes used. The electricity source assumed in those cases will vary depending on the source and assumptions of the data. Because of the global nature of many supply chains, to adjust all these datasets to reflect U.S. electrical production in all upstream processes may not add accuracy in some cases. Nevertheless, it is anticipated that several important datasets will be updated in this way for Phase 2 in an attempt to better reflect U.S. and Oregon conditions.

End-of-Life Options

All materials used in the home are assigned a fate at the time they leave the site of the home: reuse, recycling, incineration, or landfilling. The percentage of the material that is sent to each of these fates is determined by a combination of the reuse rates for the scenario in question and the typical rates for handling construction related materials in Oregon. With the exception of Deconstruction and Design for Disassembly, it has been assumed that no offsite reuse occurs. Where reuse occurs, this amount of material is first subtracted from the pool of materials to be disposed and then the rates of material heading to the other three fates are applied. Information on the percentages of materials handled by each process is provided in Appendix 13.

Reuse is assumed to occur in a way that the material replaces new material of the same type. For example, if a door is reused, it is assumed to replace a door of equivalent composition and is not prorated to reflect a reduced durability. It is assumed that the transportation needed to move the material to its new point of use are equivalent to that needed to source new materials and so no net benefit or impact is assigned regarding transport of reused materials.

Landfilling is assigned impacts based on available data regarding the disposal of material of various types in municipal waste landfills. This data is primarily from the ecoinvent database. While coverage is available for a variety of the main materials that are used, there are some materials for which a close match does not exist or where the item represented is made of a combination of materials. At this screening level, no attempt has been made to modify end-of-life data for such products and the closest available material disposal was chosen. For example, whereas exterior doors are assumed to be a combination of aluminum and other materials, they are represented at end-of-life as if they are entirely aluminum.

With regard to climate change, landfills play a role in sequestering (at least temporarily) carbon and keeping it from the atmosphere. Because the timing of any emissions in weighing their importance is not considered here, this delayed release is not accounted for as a benefit for climate change. Furthermore, ignoring the uptake of biogenic carbon and the emission of carbon dioxide requires the assumption that all carbon entering a landfill from biologically-derived sources will eventually be emitted to the atmosphere.

Recycling is handled by a system-expansion approach in which a credit is given to the system equal to the impacts of producing a virgin equivalent of the recycled material, less the impacts of recycling it. For example, when polystyrene packaging is recycled, there is a credit for virgin polystyrene less the impacts of the electricity used in processing the recycled polystyrene. For materials that are recycled in a way that does not produce the equivalent (or something close to it) of the original material, the production of a closer equivalent of the final product is used to calculate the credit. For example, when concrete is recycled, the credit given is equal to the impact of producing gravel rather than concrete because it is assumed that the concrete is crushed and used for aggregate.

Incineration is assumed to occur with partial energy recovery. It is assumed that 10% of the heat content of the materials is recaptured as electrical energy and 20% of the heat content is captured as heat energy. A credit is then applied for the production of that electricity or heat by conventional means, less the impacts of the incineration itself (e.g., emissions from the incinerator).

Allocation of Reused Materials

In the scenarios dealing with reuse of material among homes, an important methodological question arises concerning how to assign the impacts of producing or disposing of a material among the several homes of which it has been a part. If not handled with care, absurd situations can occur in which more than 100% of the credit of producing a material is applied, leading to a sink of environmental impacts. Further, there are several philosophical considerations of how to most accurately represent causation and responsibility of the impacts that are generated over the life of materials. There are a large number of methods that have been applied for handling these situations, although none are globally ideal and few are ideal within even subsets of situations.

Because the goal of this Phase 1 assessment has been to compare practices based on the potential impact each might have, choices have been made throughout the process to err on the side of favoring those processes in question. In the case of material reuse, it has been chosen to give the maximal credit possible to the system when a material is either salvaged for reuse or is being reused from a prior home. The credit is equal to the production of the material such that, on balance, materials that have been or are reused result in no impacts being assigned to the home in question.

This method is not without problems. It is not fair to the prior or later home that is giving or receiving the materials in that that home is receiving 100% of the impacts. When considering population of homes, it will therefore lead to problems. It could also lead to situations where a double credit is assigned, although there are no instances in the present set of scenarios where a material is reused for construction of the home and then salvaged for further use at demolition. It is anticipated that an alternate allocation procedure will be needed in Phase 2.

A scenario has been run with a second allocation method to test the sensitivity of the results to this choice.

Appendix 6: Sensitivity Tests

Sensitivity tests have been performed on several underlying variables or assumptions to determine to what extent the conclusions of the study depend on methodological choices that have been made. The aspects that have been tested include the following:

- The lifetime of the home. In addition to the standard assumption of 70 years, values of 30, 40, 50, 60, 80, 90, and 100 have been tested.
- The carbon intensity of electricity in the use phase and in end-of-life processes. In addition to the standard assumption that it is 0.86 kg CO_2 per kWh (reflecting the average production of the U.S. mix from ecoinvent), values of 0.2, 0.4, 0.6 (similar to the grid of the Western U.S. states), 1.0, and 1.2 (similar to use of only coal-derived electricity) have been tested.
- The allocation that is applied to materials that are salvaged from prior homes or that are taken from the present home at end-of-life for reuse in another home: In addition to the standard assumption of allocating 0% of the impact of producing salvaged material and 100% of the benefit of reusing salvaged materials to the present home, 50% has been tested for both values.
- The environmental impact metrics that are used for decision making. In addition to the climate change impact, which has been used as the basis for most results presented here and the primary basis for ranking scenarios, the other impact metrics listed in the above section have been tested.

For a discussion of the results of these sensitivity tests, see the main text of the report.

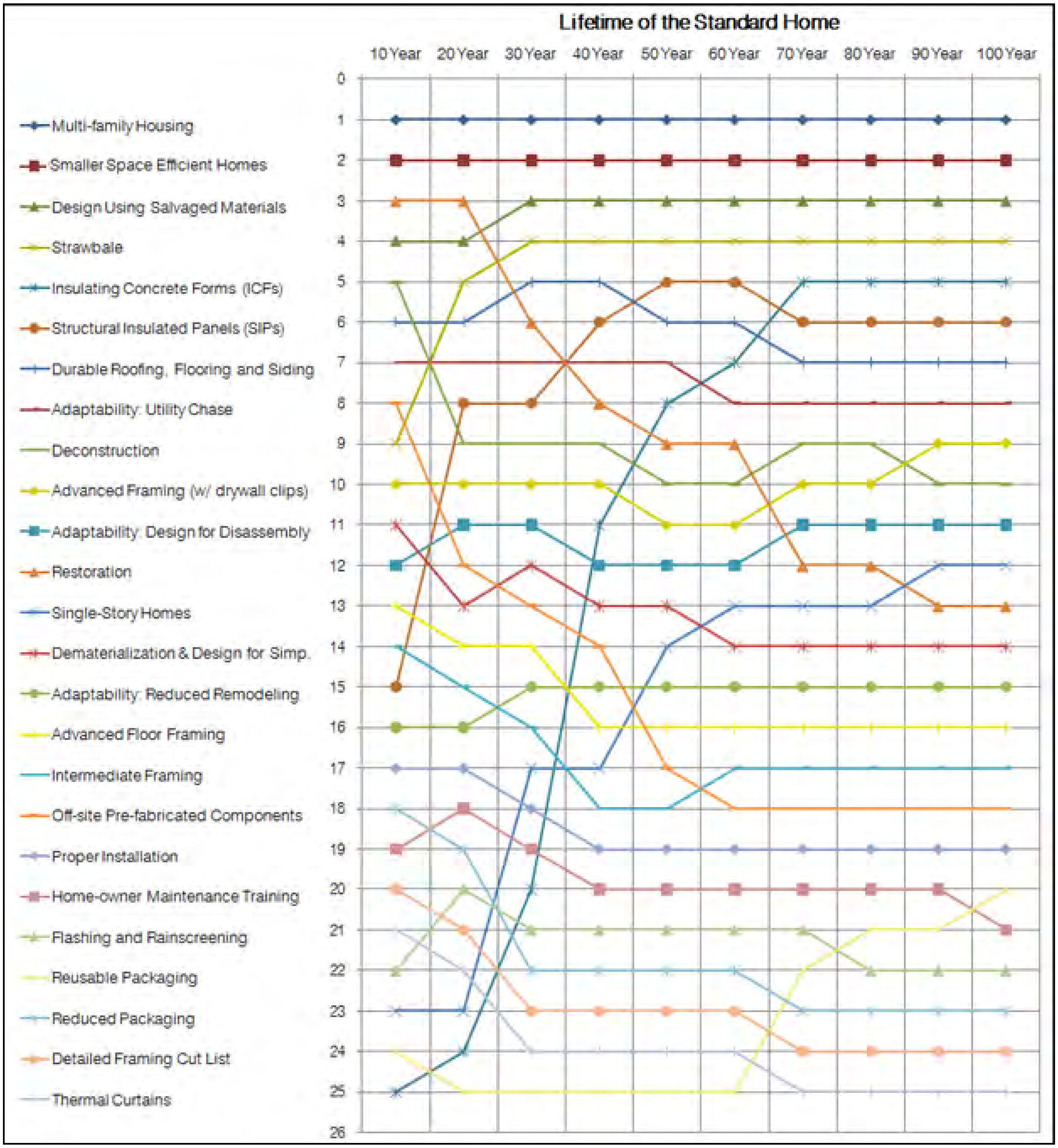


Figure 14: Changes in climate change rankings of scenarios with changes in the lifetime of the home

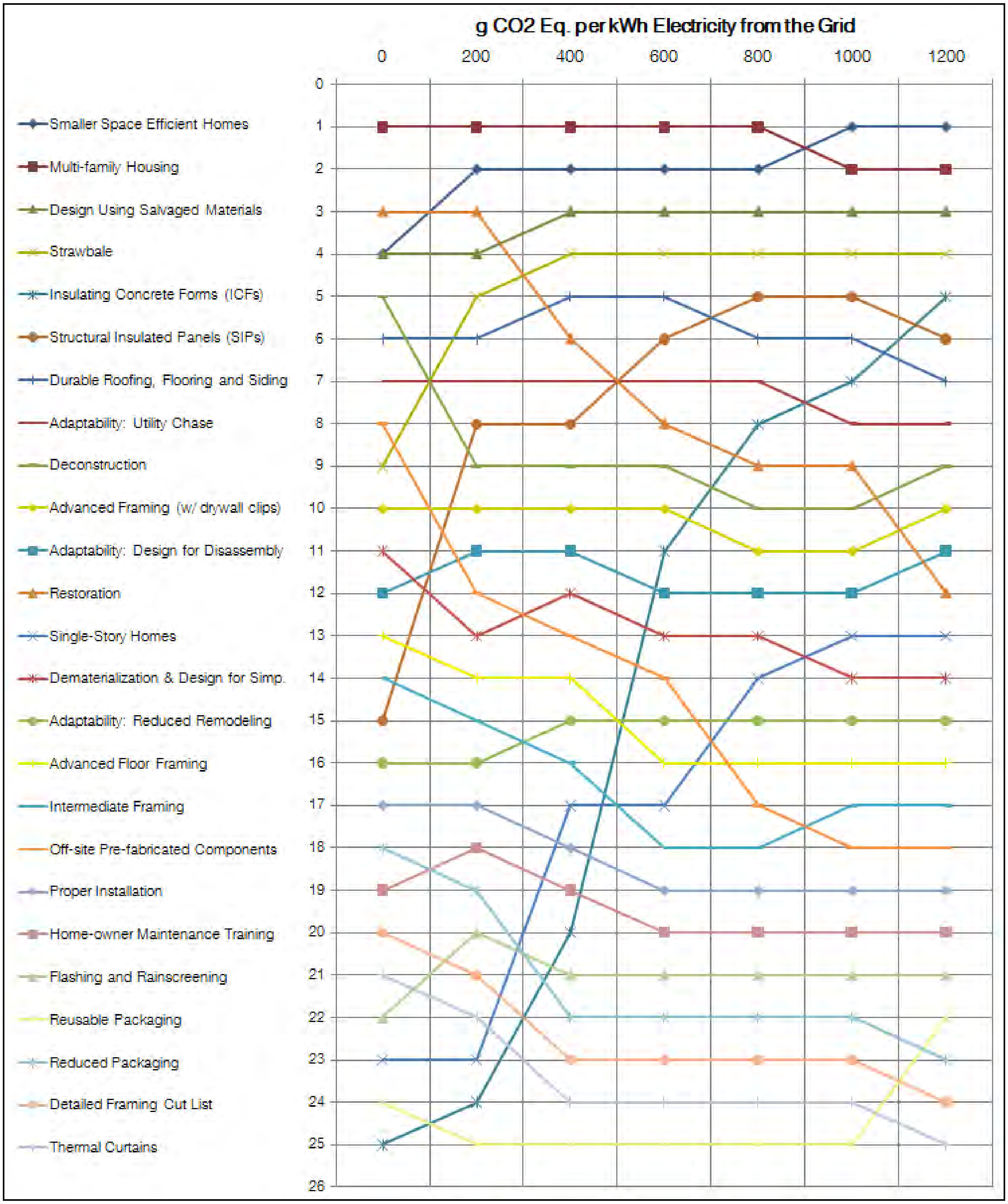


Figure 15: Changes in climate change rankings of scenarios with changes in the climate change impact of electricity

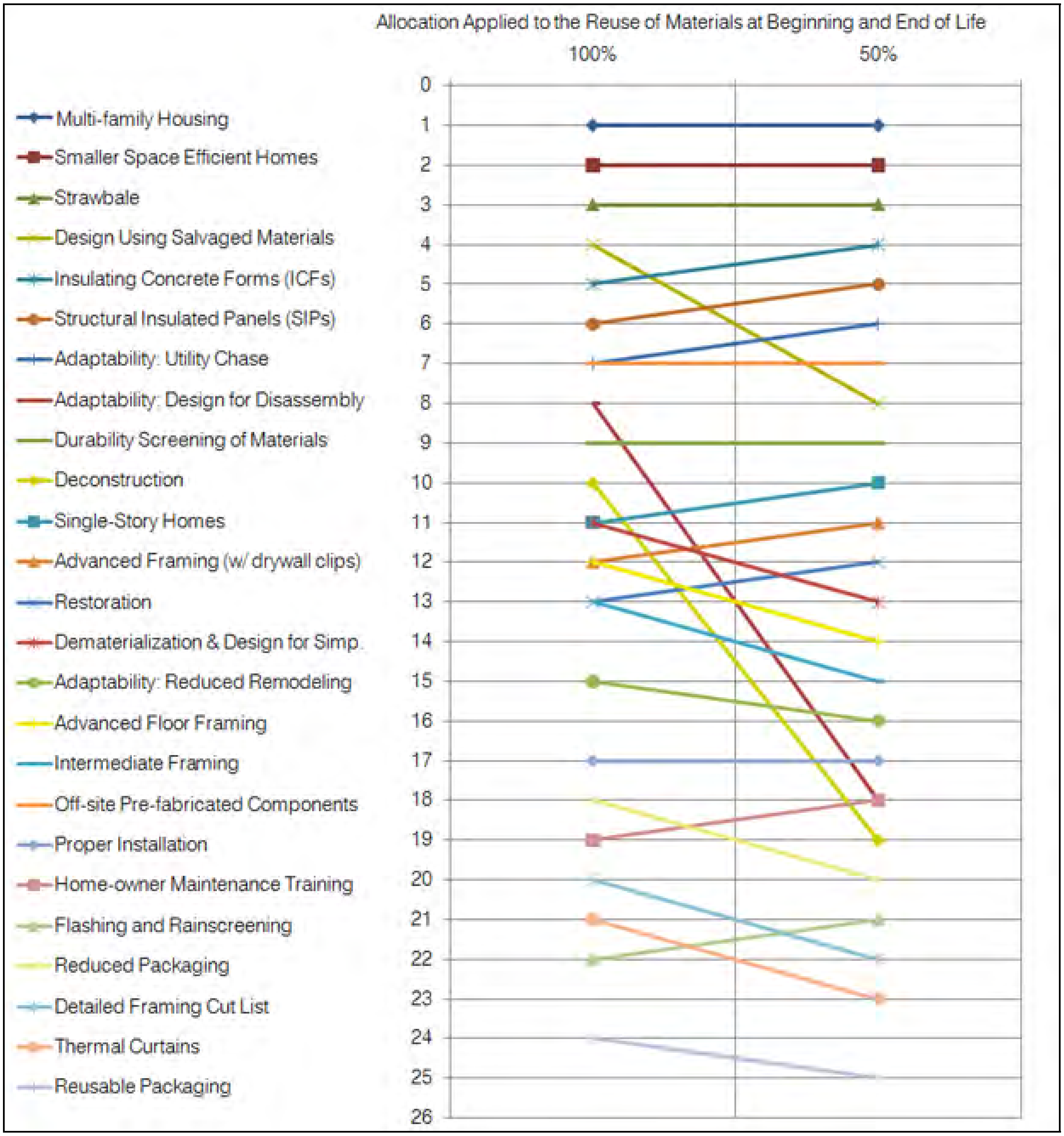


Figure 16: Changes in climate change rankings of scenarios with changes in the allocation of impacts for reused and salvaged materials

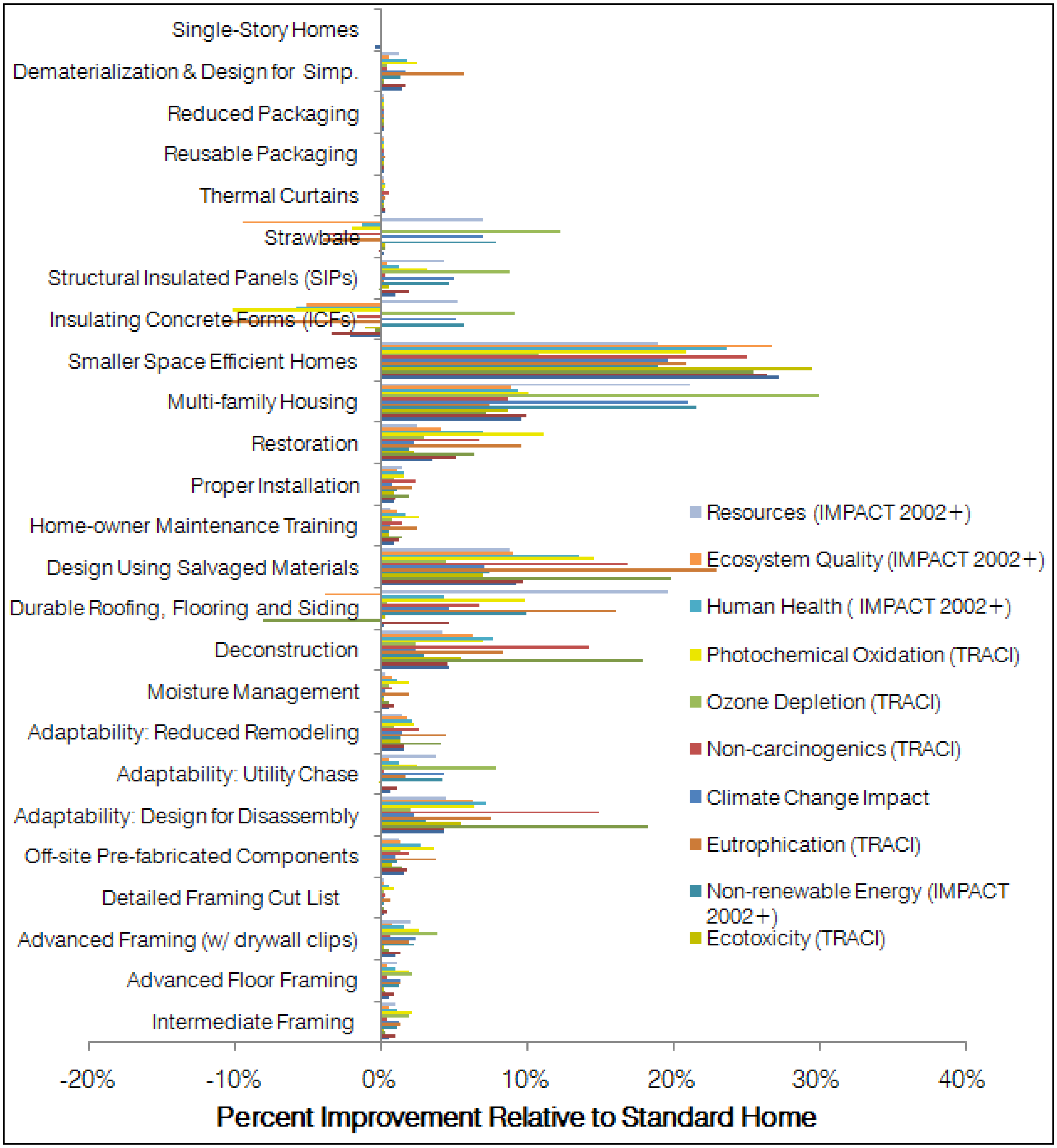


Figure 17: Percent increase and decrease in each environmental metric evaluated for each of the scenarios

Appendix 7: Reuse Rates, Waste Factors and Availability of Salvaged Materials by Material Type

See the attached MS Excel file

Appendix 8: Material Replacement Rates

See the attached MS Excel file

Appendix 9: Home Materials for Standard Home and Waste Prevention Practices

See the attached MS Excel file

Appendix 10: Summary of LCI Data Used

See the attached MS Excel file

Appendix 11: Results by Process for the Standard Scenario

See the attached MS Excel file

Appendix 12: Cost Data

See the attached MS Excel file

Appendix 13: End-of-life Fates of Material Types

See the attached MS Excel file

Appendix 14: Home Design Information

See attached file

Appendix 15: Energy Modeling Results

See attached file

Appendix 16: Oregon DEQ Advisory Committee

Appendix 17: Annotated Bibliography

Short Citation	Full Citation	Potential Use/Annotation
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Abeysundara, Babel, & Piantanakulchai, 2009	Yasantha Abeysundara, U. G., Babel, S., & Piantanakulchai, M. (2009). A matrix for selecting sustainable floor coverings for buildings in Sri Lanka. *Journal of Cleaner Production*, *17: 231–238*, from www.elsevier.com/locate/jclepro.	Method to facilitate the decision making process in selecting sustainable floors (elements) for buildings in Sri Lanka using LCA.
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Althaus, Kellenberger, Doka, & Künniger, 2004	Althaus, H. J., Kellenberger, D., Doka, G., & Künniger, T. (November 2004). Manufacturing and disposal of building materials and inventorying infrastructure in ecoinvent. *ecoinvent: Materials and Agriculture*, *10 (1), 35 – 42*. Retrieved from http://dx.doi.org/10.1065/lca2004.11.181.4	Describes the goal and scope of building material inventories in the ecoinvent database and gives an overview of the database's content.
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Jolliet, Margni, Charles, Humbert, Payet, & Rebitzer, 2002	Jolliet, O., Margni, M., Charles, R., Humbert, S., Payet, J., & Rebitzer, G. (2002). IMPACT 2002+: A new life cycle impact assessment methodology. *International Journal Life Cycle Assessment*, (6), 324–330.	Discusses IMPACT 2002+ database upgrade, focusing on the comparative assessment of human toxicity and ecotoxicity. Human damage factors are calculated for carcinogens and non-carcinogens, employing intake fractions, best estimates of dose-response slope factors, as well as severities.
Keoleian, Blanchard, & Reppe, 2001	Keoleian, G. A., Blanchard, S., & Reppe, P. (2001). Life-cycle energy, costs, and strategies for improving a single-family house. *Journal of Industrial Ecology*, *1 (2)*, 135-156.	Analyzes the life cycle energy, greenhouse gas emissions, and costs of a contemporary 2,450 sq ft (228 m3) U.S. residential home (the standard home, or SH) identify opportunities for conserving energy throughout pre-use (materials production and construction), use (including maintenance and improvement), and demolition phases.
Kline, 2005	Kline, D. E. (2005). Gate-to-gate life-cycle inventory of oriented strandboard production. *Wood and Fiber Science*, *37*, 74 – 84.	Life-cycle inventory (LCI) for Southeast oriented strandboard (OSB) manufacturing by surveying four OSB manufacturing plants in the Southeast US.
Kofoworola & Gheewala, 2008	Kofoworola, O. F., & Gheewala, S. H. (2008). Environmental life cycle assessment of a commercial office building in Thailand. *International Journal of Life Cycle Assessment*, *13*, 498-511.	Article provides an environmental life cycle assessment (LCA) of a typical commercial office building in Thailand.
Krogmann, Minderman, Senick, & Andrews, 2008	Krogmann, U., Minderman, N., Senick, J., & Andrews, C. (2008). *Life-Cycle assessment of the New Jersey meadowlands, Commission Center for Environmental and Scientific Education Building*. New Brunswick,	LCA of large institutional building

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	New Jersey: The Rutgers Center for Green Building.	
Kulongoski, 2008	Kulongoski, T. (November 2008). *Answering the Oregon challenge: Climate change.* Salem, Oregon: Oregon Governor's Office.	Description of governor's climate change legislative agenda for Oregon 2009 Legislative Session.
Lippiatt & Boyles, 2001	Lippiatt, B. C., & Boyles, A. S. (2001). Using BEES to select cost-effective green products. *International Journal of Life Cycle Assessment*, *6*(2), 76-80.	Describes the BEES ((Building for Environmental and Economic Sustainability) software, which allows assessment of the environmental and economic performance of building products.
Lippke, Wilson, Perez-Garcia, Bowyer, & Meil, 2004	Lippke, B., Wilson, J., Perez-Garcia, J., Bowyer, J., & Meil, J. (June 2004). CORRIM: Life-cycle environmental performance of renewable building materials. *Forest Products Journal*, *54*(6), 8-19.	Describes how the Consortium for Research on Renewable Industrial Materials (CORRIM) to undertake research on the use of wood as a renewable material. Describes development of a life-cycle assessment (LCA) for residential structures and other wood uses.
Lippke & Edmonds, 2005	Lippke, B., & Edmonds, L. (October 2005). Environmental performance improvement in residential construction: The impact of products, biofuels, and processes. *Forest Products Journal*, *55 (10)*, 59-63.	Previous study by Consortium for Research on Renewable Industrial Materials (CORRIM) evaluated the life cycle environmental impacts of building materials used in residential construction. This report builds upon those findings by examining the environmental burdens of each component used to construct wall and floor subassemblies in residential homes. Evaluating components and subassemblies illuminates how the environmental burdens from different products, designs, and processes compare.
Louisiana-Pacific Corporation, 2008	Louisiana-Pacific Corporation. (2008). *LP® SolidStart® I-JOISTS LPI® 18 Technical guide, floor & roof applications*. USA: Louisiana-Pacific Corporation.	I-Joist Factsheet, LP SolidStart
Lstiburek, 2005	Lstiburek, J. (October/November 2005). The future of framing. *Fine Homebuilding*, 50-55.	Extols the benefits of wood in building construction. Discusses recent improvements in building design and construction that use wood.
Meil, Lucuik, O'Connor, & Dangerfield, 2006	Meil, J., Lucuik, M., O'Connor, J., & Dangerfield, J. (September 2006). A life cycle environmental and economic assessment of optimum value engineering in houses. *FOREST PRODUCTS JOURNAL*, *56 (9)*, 19-25.	Study tests the hypothesis that reducing or substituting forest products (mainly wood) for alternative, non-wood materials provides an environmental benefit. Uses LCA approach to compare a conventional Canadian house to two case study houses: 1. house using up to 50% less wood; 2. house that combined some elements of efficient framing with maximum use of renewable content (e.g., cellulose insulation in place of fiberglass, wood windows in place of aluminum windows, and wood siding in place of vinyl siding). House 1 had little or no environmental benefit. House 2 exhibited significant environmental benefit, suggesting that maintaining, not decreasing renewable content in building construction is important.
METRO: Solid	METRO: Solid Waste Department. (July 1993).	Assessment of solid waste from new

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Waste Department, 1993a	*Characterization of construction site waste* (Contract No. 902906). Portland, Oregon: METRO.	residential and commercial construction within the Portland metro area.
METRO: Solid Waste Department, 1993b	METRO: Solid Waste Department. (July 1993). *Construction industry recycling project.* Portland, Oregon: METRO.	Assessment of an educational, promotional campaign on resource-efficient building practices & materials.
METRO, 1993	METRO. (June 1993). *Residential remodeling waste reduction demonstration project* (Contract No.902741). Portland, Oregon: METRO.	Report on a project to develop, document, and teach cost effective waste reduction techniques for residential remodeling projects. Three project types assessed: Kitchen, Family Room/Kitchen, Bathrooms. Wastes generated during each project's demolition and construction phases were audited to determine the weight and type according to standard classifications used by METRO. Materials that could be diverted were identified and their disposition was recorded. Diversion was defined as source separation, salvage and reuse, and recycling. No effort was made to affect the design or construction of the projects to reduce waste generation.
Milota, West, & Hartley, 2005	Milota, M. R., West, C. D., & Hartley, I. D. (2005). Gate-to-gate life-cycle inventory of softwood lumber production. *Wood and Fiber Science*, *37*, 47 – 57.	Life cycle inventory of softwood lumber in the Western and Southern United States.
Mithraratne & Vale, 2004	Mithraratne, N., & Vale, B. (2004). Life cycle analysis model for New Zealand houses. *Building and Environment*. *39*, 483-492.	Paper describes a method that has been developed at the University of Auckland for a detailed life cycle analysis of an individual house in New Zealand based on the embodied and operating energy requirements and life cycle cost over the useful life of the building.
EPA, 1997	U.S. Environmental Protection Agency: The Urban and Economic Development Division. (June 1997). *Deconstruction - Building disassembly and material salvage: The Riverdale case study*. Upper Marlboro, Maryland.	Deconstruction and disassembly of 2,000 sq. ft. multifamily (4 unit) building in 27-acre Riverdale neighborhood, urban area of Baltimore.
NAHBRC, 1997	National Association of Home Builders Research Center. (1997). *Deconstruction -Building disassembly and material salvage: The Riverdale case study.*	Information on disassembly and use of salvaged materials
NCSC, 200	North Carolina Solar Center. (2002, June). *Passive solar home design checklist*. Raleigh, North Carolina: North Carolina Solar Center.	Extols the benefits of passive solar design. Discusses important design requirements to maximize passive solar benefits.
NEEA, 2007a	Northwest Energy Efficiency Alliance. (2007, August). *Single-family residential existing construction stock assessment*. Sonoma, California: RLW Analytics.	Single-family residential existing construction stock characteristics
NEEA, 2007b	Northwest Energy Efficiency Alliance. (2007, March). *Single-family residential new construction characteristics and practice study: Final report* [Brochure]. Sonoma, California: RLW Analytics.	Single-family residential new construction stock characteristics and practices study
NEEA, 2007c	Northwest Energy Efficiency Alliance. (2007, October). *Residential new construction (single and multifamily) billing analysis* [Brochure]. Sonoma, California: RLW Analytics: RLW Analytics	Residential New Construction (Single and Multifamily) Billing Analysis - contains average new construction energy
NPCC, 2005	Northwest Power and Conservation Council. (2005, May). *The fifth Northwest electric power and conservation plan*. Portland, Oregon: NPCC. Retrieved	Comprehensive plan for electric power generation in Northwest US. The appendices contain a wealth of data.

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	online from http://www.nwcouncil.org/energy/powerplan/5/Default.htm	
O'Brien, Guy, & Linder, 2006	O'Brien, E., Guy, B., & Linder, A. (2006). Life cycle analysis of the deconstruction of military Barracks: Ft. McClellan, Anniston, AL. *Journal of Green Building, 1*(4), 166-183.	Report on the LCA for manual deconstruction of military barracks at Ft. McClellan in Anniston, Alabama. Several manual deconstruction scenarios were compared. Study compared manual deconstruction to mechanical demolition. Found materials salvaged using either 100% or 44% manual deconstruction and reused within a 20-mile radius of the deconstruction site yielded the most favorable environmental and health impacts.
ODEQ, 2007	Oregon Department of Environmental Quality (2007, February). *Waste prevention strategy – Background paper #1 solid waste generation in Orego*n. p. 2	
Ortiz, Francesco, & Sonnemann, 2009	Ortiz, O., Francesco, C., & Sonnemann, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Construction and Building Materials*, *23*. Retrieved from http://www.sciencedirect.com	LCA of construction practices in the construction industry
Osman & Ries, 2007	Osman, A., & Ries, R. (2007). Life cycle assessment of electrical and thermal energy systems for commercial buildings. *International Journal of Life Cycle Assessment. 12 (5)*, 308–316.	Article addresses developing LCA models for energy systems in order to assess the potential environmental impacts that might result from meeting energy demands in buildings. The scope of the study includes LCA models of the average electricity generation mix in the USA, a natural gas combined cycle (NGCC) power plant, a solid oxide fuel cell (SOFC) cogeneration system; a microturbine (MT) cogeneration system; an internal combustion engine (ICE) cogeneration system; and a gas boiler.
Passer, Cresnik, Schulter, & Maydl, 2007	Passer, A., Cresnik, G., Schulter, D., & Maydl, P. (2007). Life cycle assessment of buildings comparing structural steelwork with other construction techniques. *2007 Life Cycle Management Conference.*,	LCA shows the results of a pre-feasibility study to identify future calls for actions for the construction industry towards sustainability: Three office buildings with load bearings systems made of reinforced concrete, steel and timber were compared.
Paulsen & Borg, 2003	Paulsen, J. H., & Borg, M. (2003). A building sector related procedure to assess the relevance of the usage phase. *International Journal of Life Cycle Assessment*, *8 (3)*, 142-150.	Concern that there is a lack of structured procedures to include a building's use-phased impacts in LCA studies. Article develops a procedure for assessing the relevance and the possibility to include the usage. Phase 1 is proposed in a structured way. Considerable effort has also been put into explaining the underlying obstacles of today's practice in handling the connection between the choice of building products and its resulting impacts in the usage phase.

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Pennington et al., 2004	Pennington, D. W., Potting, J., Finnveden, G., Lindeijer, E., Jolliet, O., Rydberg, T., et al. (2004). Current impact assessment practice. *Life cycle assessment Part 2: Environment International*, *30* pp. 721-739.	Article highlights how practitioners and researchers from many domains have come together to provide indicators for the different impacts attributable to products in the life cycle impact assessment (LCIA) phase of life cycle assessment (LCA).
Perez-Garcia, Lippke, Briggs, Wilson, Bowyer, & Meil, 2005	Perez-Garcia, J., Lippke, B., Briggs, D., Wilson, J.B., Bowyer, J., & Meil, J. (2005). The Environmental performance of renewable building materials in the context of residential construction. *Wood and Fiber Science. 37*, 3 – 17.	Life cycle assessment (LCA) of alternative building materials from forest resource regeneration or mineral extraction through product manufacturing, the assembly of products in constructing a residential home, occupancy and home repairs, and the eventual disposal or recycle.
Peuportier, 2001	Peuportier, B. L. P. (2001). Life cycle assessment applied to the comparative evaluation of single family houses in the French context. *Energy and Buildings*, *22*, 443-350.	Life cycle simulation tool is developed and linked with thermal simulation. Using the LCA simulation tool, three houses are evaluated: the present construction standard in France (reference), a solar, and a wooden frame house.
Puettmann & Wilson, 2005a	Puettmann, M. E., & Wilson, J. B. (2005). Life-cycle analysis of wood products: Cradle-to-gate LCI of residential wood building materials. *Wood and Fiber Science*, *37*, 18-29.	Compares cradle-to-gate total energy and major emissions for the extraction of raw materials, production, and transportation of the common wood building materials from the CORRIM 2004 reports. A life cycle inventory identified the raw materials, including fuel resources and emission to air, water, and land for glued-laminated timbers, kiln-dried and green softwood lumber, laminated veneer lumber, softwood plywood, and oriented strandboard.
Puettmann & Wilson, 2005b	Puettmann, M. E., & Wilson, J. B. (2005). Gate-to-gate life-cycle inventory of glued-laminated timbers production. *Wood and Fiber Science*, *37*, 99 – 113.	Full gate-to-gate life cycle inventory for the production of glued-laminated timbers (glu-lam) produced in two regions of the United States: the Pacific Northwest and Southeast. Data collected from surveys of manufacturers are presented for energy requirements, raw materials use, and emissions to land, water, and air allocated for one cubic meter and 1,000 cubic feet of glu-lam.
Rebitzer et al. 2004	Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G. Rydberg, T., et al. (2004). Life cycle assessment Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environment International*, *30*, 701-720.	Part 1 in a series of two, this paper introduces the LCA framework and procedure, outlines how to define and model a product's life cycle, and provides an overview of available methods and tools for tabulating and compiling associated emissions and resource consumption data in a life cycle inventory (LCI). It also discusses the application of LCA in industry and policy making.
Sartori & Hestnes, 2007	Sartori, I., & Hestnes, A. G. (2007). Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings*, *39*. Retrieved from http://www.sciencedirect.com.	Literature review of a building's LCA energy use. Includes review of 60 buildings in 9 countries.

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Scheuer & Keoleian, 2002	Scheuer, C. W., & Keoleian, G. A. (September 2002). *Evaluation of LEED using life cycle assessment methods*. Gaithersburg, Maryland: U.S. Department Of Commerce.	Detailed & lengthy report on using LCA to evaluate LEED.
Schmidt, Jensen, Clausen, Kamstrup, & Postlethwaite, 2004	Schmidt, A. C., Jensen, A. A, Clausen, A. U., Kamstrup, O., & Postlethwaite, D. (2004). A comparative life cycle assessment of building insulation products made of stone wool, paper wool and flax - Part 2 Comparative assessment. *International Journal of Life Cycle Assessment*, *9(2)*, 122-129.	LCA information on insulation materials
Shah, Col Debella, & Ries, 2008	Shah, V.P., Col Debella, D., & Ries, R.J. (2008). Life cycle assessment of residential heating and cooling systems in four regions in the United States. *Energy and Buildings*, *40: 503-513*. Retrieved from http://www.sciencedirect.com.	Home HVAC systems responsible for most energy consumption & emissions of all home systems. Compares LCA impacts of 3 types HVAC in 4 U.S. locations over 35 year life.
Shami, 2006	Shami, M. (2006). A comprehensive review of building deconstruction and salvage: Deconstruction benefits and hurdles. *International Journal Environmental Technology and Management*, *6 (3/4)*, 236-291.	Paper addresses the benefits of building deconstruction as an alternative to building demolition. Discusses technical, environmental, and socioeconomic issues of deconstruction.
Sharrard, 2007	Sharrard, A. (2007) Greening Construction Processes Using an Input-Output-Based Hybrid Life Cycle Assessment Model. PhD Thesis, Carnegie Mellon University	Thesis includes a wide variety of information regarding construction practices, combined with an economic input-output approach to quantifying environmental impacts
University of Alaska, 2006	University of Alaska, Fairbanks Cooperative Extension Service. (2006, November). *Passive solar heating: An energy factsheet* (EEM-01258). Fairbanks, Alaska: University of Alaska.	Brochure debunks the misconception that passive solar building design cannot be accomplished in Alaska. Provides information on the value of passive solar design in Alaska as an efficient & inexpensive method to heat buildings.
Unknown, 2006	Unknown. (2006, December). *Design for disassembly in the built environment: DfD case study home: 71 Boulevard, Atlanta, GA 30312*.	Case study of a house that has been designed for future disassembly. Includes recommendations and advice on what to consider when designing a building for disassembly.
University of Florida, 2003	University of Florida: Powell Center for Construction and Environment. (2003, January). *Final report: Design for deconstruction and reuse.* Gainesville, Florida: University of Florida.	Report on the benefits of designing buildings for deconstruction. Addresses the dangers of current building design process & application. Assessed old building waste & new building design. Used cases studies for deconstruction of an old building and a new building using deconstructed materials from the old building.
Upton, Miner, Spinney, & Heath, 2008	Upton, B., Miner, R., Spinney, M., & Heath, L. S. (2008). The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States. *Biomass and Bioenergy*, *32m, 1-10*. Retrieved from http://www.elsevier.com/locate/biombioe	Article estimates savings of greenhouse gas emissions and energy consumption associated with use of wood-based building materials in residential construction in the United States. Using LCA for energy consumption & GHG emissions compares wood based building construction to other construction materials (masonry, steel).

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US DOE, 2000a	U.S. Department of Energy, Office of Building Technology, State and Community Programs, Office of Energy Efficiency and Renewable Energy. (2000, October). *Advanced wall framing: Build efficiently, use less material, and save energy!* (DOE/GO-102000-0770). Washington, D.C.: U.S. DOE.	Advanced framing techniques
US DOE, 2000b	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. (2000, November). *Passive solar design:* (DOE/GO-102000-728). Golden, Colorado: US Department of Energy.	Brochure on incorporation of passive solar measures in federal facilities.
US DOE, 2000c	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. (2000, December). *Passive solar design: Increase energy efficiency and comfort in homes by incorporating passive solar design features* (DOE/GO10099-790). Washington, D.C.: U.S. DOE.	Booklet with information on passive solar design benefits & design requirements.
US DOE, 2001	U.S. Department of Energy, National Renewable Energy Laboratory. (2001, February). *Passive solar design for the home* (DOE/GO-102001-1105). Washington, D.C.: U.S. DOE.	Brochure with information on passive solar design for houses.
US EPA, 1998	U.S. Environmental Protection Agency: Municipal and Industrial Solid Waste Division. (1998, June). *Characterization of building-related construction and demolition debris in the United States.* Office of Solid Waste (Report No. EPA530-R-98-010). Washington, D.C.: U.S. EPA.	Report characterizes the quantity and composition of building related construction and demolition (C&D) debris generated in the United States, and summarizes the waste management practices for this waste stream. C&D debris is produced when new structures are built and when existing structures are renovated or demolished.
US EPA, 2003	U.S. Environmental Protection Agency. (2003). *Estimating 2003 building-related construction and demolition materials amounts.* Washington, D.C.: U.S. EPA.	The purpose of this study is to determine the amount of building-related C&D (construction and demolition) materials generated and recovered in the U.S. during 2003, and updating the findings of the 1998 EPA report, *Characterization of Building-Related Construction and Demolition Debris in the United States* (EPA 530-R-98-010). C&D materials are generated when new structures are built and when existing structures are renovated or demolished (including deconstruction activities).
US HUD, 2000	U.S. Department of Housing and Urban Development, Office of Policy Development and Research. (February 2000). *A guide to deconstruction.* Washington, D.C.: U.S. Department of Housing and Urban Development.	Report on building deconstruction opportunities as a way to reduce waste as well as provide economic benefits, job training, environmental improvement, etc.
Utama & Gheewala, 2008	Utama, A., & Gheewala, S. H. (2008). Influence of material selection on energy demand in residential houses. *Journal Materials and Design*. Retrieved from http://www.elsevier.com/locate/matdes. doi:10.1016/j.matdes.2008.08.046.	Article using LCA assesses utilizing local materials for improving the energy demand in the single landed houses in Indonesia.
Werner & Richter, 2007	Werner, F., & Richter, K. (2007). Wooden building products in comparative LCA: A literature review. *International Journal of Life Cycle Assessment: A Literature Review*. *12 (7)*, 470–479.	Review LCA literature on results of approximately 20 years of international research on the environmental impact of the life cycle of wood products used in the building sector compared to functionally equivalent products from

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		other materials.
Wilson & Dancer, 2005a	Wilson, J. B., & Dancer, E. R. (2005). Gate-to-gate life-cycle inventory of laminated veneer lumber production. *Wood and Fiber Science*, *37*, 114-127.	A life cycle inventory (LCI) study of laminated veneer lumber (LVL) manufacturing. Gate-to-gate study includes all environmental impacts from the logs to produce either veneer or parallel laminated veneer (PLV) as input to the LVL process, through production of the LVL. The study includes all materials, fuels, and electricity inputs to produce LVL and related co-products and emissions.
Wilson & Dancer, 2005b	Wilson, J. B., & Dancer, E. R. (2005). Gate-to-Gate life cycle inventory of I-joist production. *Journal of Wood and Fiber Science*, *37*, 85-94.	LCI data on I-joist beams.
Wilson & Sakimoto, 2005	Wilson, J. B., & Sakimoto, E. T. (2005). Gate-to-gate life-cycle inventory of softwood plywood production. *Wood and Fiber Science*, *37*, 58-73.	Article on life cycle inventory (LCI) of softwood plywood manufacturing. Gate-to-gate study includes all materials, fuels, and electricity inputs to produce plywood, co-products, and emissions.
Winistorfer, Chen, Lippke, & Stevens, 2005	Winistorfer, P., Chen, Z., Lippke, B., & Stevens, N. (2005). Energy consumption and greenhouse gas emissions related to the use, maintenance, and disposal of a residential structure. *Wood and Fiber Science*, *37*, 128-139.	Virtual residential houses in Atlanta, Georgia, and Minneapolis, Minnesota, were analyzed to determine energy consumption and greenhouse gas emission during the building use, maintenance, and demolition phases of their life cycle.
Wittstock, Makishi, Braune, Kreissig, Gallon, & Wetzel, 2007	Wittstock, B., Makishi, C., Braune, A., Kreissig, J., Gallon, N., & Wetzel, C. (2007). Identifying environmental improvement potentials of residential buildings. *2007 Life Cycle Management Conference.*	Addresses options to reduce the environmental impacts from residential dwellings throughout their entire life cycle. The main objective of the study is to outline the current situation of residential buildings in the EU-25, to assess environmental improvement options for new and existing buildings and to evaluate the improvement potentials from a European perspective.
Washington State University, 2006	Washington State University Extension Energy Program. (2006). "Framing," in *WSEC builder's field guide* (7th ed.). Washington State University Extension Energy Program.	Discussion of different kinds of framing techniques and construction materials, as well as doors & windows.
AHS Web site a	U.S. Census Bureau. (2009). *American housing survey*. Retrieved June, 10, 2009, from http://www.census.gov/hhes/www/housing/ahs/ahs.html	Website with data and information on the US Census Bureau's American Housing Surveys
AHS Web site b	U.S. Census Bureau. (2009). *2002 AHS metropolitan alterations and replacements*. Retrieved June, 10, 2009, from http://www.census.gov/hhes/www/housing/ahs/ahs02alt/portland/tab1-3.html	AHS page on home remodeling data.
BECRC Web site a	Building Energy Codes Resource Center. (2009). *Drywall clips - code notes*. Retrieved June, 10, 2009, from http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//133	Web site with an article on the use of drywall clips in wall construction.
BECRC Web site b	Building Energy Codes Resource Center. (2009). *Advanced framing*. Retrieved June, 10, 2009, fromhttp://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1399.	Web site with an article on the use of advanced framing in building construction.

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EAI Web site	Energy Information Administration. (2009). Consumption, price and expenditure estimates: State energy data system (SEDS). Retrieved June, 10, 2009, from http://www.eia.doe.gov/emeu/states/_seds.html.	Official energy statistics from U.S. government.
ICFA Web site	Insulating Concrete Form Association. (2009). Retrieved June, 10, 2009, from http://www.forms.org/index.php.	Trade association Web site providing resources regarding ICFs.
McCoy's Web site a	McCoy's Building Supply. (2009). *What is deconstruction?* Retrieved June, 10, 2009, from http://www.mccoys.com/library/construction-and-demolition-debris-management-deconstruction. I	Article that explains building deconstruction with links to other related articles.
McCoy's Web site b	McCoy's Building Supply. (2009). *Advanced framing techniques*. Retrieved June, 10, 2009, from http://www.mccoys.com/Library/Advanced-Framing-Techniques.	Article that explains advanced framing techniques with links to other related articles.
McCoy's Web site c	McCoy's Building Supply. (2009). *Using passive solar heating in your home*. Retrieved June, 10, 2009, from http://www.mccoys.com/library/using-passive-solar-heating-your-home.	Article on passive solar heating in homes.
McCoy's Web site d	McCoy's Building Supply. (2009). *Less is more: Demand a house with less framing, less waste, and better performance.* Retrieved June, 10, 2009, from http://www.mccoys.com/library/Less+is+More%3A+Demand+a+House+with+Less+Framing%2C+Less++Waste%2C+and+Better+Performance+	Article on using fewer materials to build a house.
PCA Web site	Portland Cement Association. (2009). *Concrete homes*. Retrieved June, 10, 2009, from http://www.cement.org/homes/ch_bs_icf.asp. Internet; accessed 10 June 2009	Trade association providing information on the benefits of Portland cement in the building industry.
SIPA Web site	Structural Insulated Panel Association. (2009). *SIP R-values (Calculated R-Values).* Retrieved June, 10, 2009, from http://www.sips.org/content/technical/index.cfm?PageId=159.	Trade association Web site addressing the benefits of SIPs.
UM Web site	Center for Sustainable Building Research, College of Architecture and Landscape Architecture, University of Minnesota (2009). *Minnesota building materials database: A tool for selecting sustainable materials*. Retrieved June, 10, 2009, from http://www.buildingmaterials.umn.edu/index.html.	Web page providing resources, links, and a tool for selecting sustainable building materials
VC Web site	Ventura County, California. (2009). *Commercial recycling, green business*. Retrieved June, 10, 2009, from http://portal.countyofventura.org/portal/page?_pageid=876,1708604&_dad=portal&_schema=PORTAL	Article on Ventura's experience with recycling building construction and demolition waste.
Wikipedia, 2009	Insulating concrete forms. (June 2009). In *Wikipedia, the free encyclopedia*. Retrieved June 10, 2009, from http://en.wikipedia.org/wiki/Insulated_concrete_forms.	Wikipedia article on ICFs.