ECONorthwest
ECONOMICS • FINANCE • PLANNING

DATE: May 15, 2020
SUBJECT: **Value of CO_2 emissions reductions through building restoration**

Restore Oregon engaged ECONorthwest to estimate the average range of values of CO_2 emission reductions one would get by renovating an existing building rather than demolishing it and building a replacement that is twice the size. This memo answers that question, but first summarizes a review of the literature.

ECONorthwest read construction, engineering, economic, and scientific literature on the building CO_2 issue. We then reached out to experts with questions specific to the interest of Restore Oregon.

Background Information

Research on energy savings in construction is unusually complicated. Beginning with there not being a uniform measure of construction; there're no average buildings, no average climates, an average location or materials. Often studies assume the replacement building would be different in type and scope. All this further confounds researching the extent you count energy use.

ECONorthwest sorted through dozens of research papers, books, and reports. Most of the research focused on hypothetical buildings, single, unique buildings, or small samples of actual projects. ECONorthwest considered all of these. However, the best answer to the question posed by Restore Oregon came from a few objective studies, and particularly one that measured CO_2 emissions for a large number of actual building projects.

It is important first to understand that there are two stages of energy use in building construction: operational and embodied.

Operational energy is the energy a building needs throughout its service life. This includes day-to-day draws from lighting, heating, cooling, ventilating systems, and appliance functions. Since this measurement continues over the life of the building, which can be anywhere from 50 to 100 years, it makes up a larger portion of the total energy ultimately used.

Embodied energy is all of the energy used constructing a building, including the creation of materials and building components as well as their transportation to the site. According to the Urban Land Institute's Greenprint Center for Building Performance,

> "In some cases embodied carbon can account for as much as half of a building's total carbon footprint over its lifetime... Unlike operational carbon, embodied carbon cannot be reduced in materials once a building's construction is complete" (ULI Americas 1).

To explore these differences further, we analyzed several studies that employed different methodologies from life-cycle analyses to discussions of low-cost opportunities to reduce emissions.

The studies reviewed did not have a consistent definition of what counted as embodied energy. Many excluded one or more CO_2 emitting stages such as site preparation, interior finishes, foundations, exterior cladding, and shipping/trucking. Some did not count the embodied energy used tearing down the existing building or considered a replacement building substantially dissimilar to the old building. Research comes from many countries, and units of measure, building standards, and construction systems vary from one another. Restore Oregon needed an answer applicable to how we in Oregon do construction.

For ECONorthwest's analysis, we chose a study covering hundreds of actual building projects in the U.S. that incorporated all stages affecting embodied CO_2. The study chosen (Strain) was done jointly with Skanska, a major construction firm, using data from FW Dodge and a model from Carnegie Mellon University. The savings from doing renovation over demolition and rebuilding varies by size of the building and whether it is wood frame or not. We sought an average.

Recall that the question posed by Restore Oregon is "estimate the average range of values of CO_2 emission reductions one would get by renovating an existing building rather than demolishing it and building a replacement." How much operational energy is saved through renovation or replacement depends mostly on the materials and systems installed, whether it is for a new or renovated structure. Thus, the crux of the answer to Restore Oregon's question falls to the differences in embodied energy.

Avoided impacts is a term used to describe the difference between the embodied energy used tearing down and replacing a historic building and restoring that building. A report discussing the United Nations campus renovation (Adlerstein) summarized this as follows

- "In the Avoided Impacts approach, embodied energy and carbon are estimated for the demolition of the existing structure and for the proposed construction of a new replacement structure. This embodied energy/carbon is considered the "avoided impact" that is not spent if a renovation is undertaken. Under this assessment, if the new building uses less operating energy than the renovation (a reasonable assumption), a calculation can be performed to determine the number of years it takes for the new construction to "recoup" the initial embodied energy/carbon investment through its operational energy and carbon savings" (7).
- This embodied energy value can then be compared to the potential improvement in energy efficiency obtained from building new. Ultimately, the number of years it would take for the new, more efficient building to "recoup" the embodied energy of demolition and new construction is defined.

Analysis

ECONorthwest chose to use the comprehensive results from a study (Strain 4-5) that measured the embodied CO_2 emissions of over 1,000 actual U.S. construction projects. They reported the avoided impacts in pounds per square foot. They assume the replacement building would be similar in type and size to the restored. We priced the CO_2 emission reductions using the mid-level pathway reported by the California Energy Commission.[1] The values were adjusted for inflation and are shown in this report in 2020 dollars.

[1] "Oregon's Cap-and-Trade Program (HB 2020): An Economic Assessment." Berkeley Economic Advising and Research. Page 52.

Emissions Savings per Square Foot

Using the study by Strain, ECONorthwest calculated the reduction in CO_2 emissions in pounds per square foot for four common building types. Our research finds in the United States that renovating a house saves between 30 and 140 pounds of CO_2 emissions over the alternative of tearing down and replacing with an identically sized home. On average, the value of those savings is $833.92 per 1,000 square feet. In the projects analyzed, similar savings were found for other small, light structures.

The avoided impacts renovating commercial buildings range from 110 to 180 pounds of CO_2 emissions per square foot. That equals a value ranging from $1,079.19 to $1,765.96 per thousand square feet. These buildings typically have more energy intensive components such as concrete and brickwork than do wood-framed houses and other light structures.

Large, heavy buildings save between 110 and 220 pounds per square foot. For every 1,000 SF of building replaced with an identical size structure, the value of CO_2 emissions savings ranges from $1,079.19 and $2,158.39 for an average of $1,618.79. These structures use more steel and concrete, involve more excavating, and fuel consumed in the shipping in the overall construction process.

Table 1: Social Cost of CO2 Emissions Reduction per Thousand Square Feet of Building Renovated Rather than Replaced, 2020 $

	Lbs. of CO2/SF Saved		Dollar Value per 1,000 SF		
Building Types	**Low**	**High**	**Low**	**High**	**Average**
Residential home	30	140	$294.33	$1,373.52	$833.92
Small, light buildings	50	120	490.54	1,177.30	833.92
Commercial buildings	110	180	1,079.19	1,765.96	1,422.58
Large, heavy buildings	110	220	1,079.19	2,158.39	1,618.79

The avoided impacts renovating commercial buildings range from 110 to 180 pounds of CO_2 emissions per square foot. That equals a value ranging from $1,079.19 to $1,765.96 per thousand square feet. These buildings typically have more energy intensive components such as concrete and brickwork than do wood-framed houses and other light structures.

Large, heavy buildings save between 110 and 220 pounds per square foot. Over a 1,000 SF the value of CO_2 emissions savings ranges from $1,079.19 and $2,158.39 for an average of $1,618.79. These structures use more steel and concrete, involve more excavating, and fuel consumed in the shipping in the overall construction process.

Example Situations

Restore Oregon observes that in the majority of situations, new buildings are larger than the historic buildings they replace. Restore Oregon asked ECONorthwest to calculate the emissions saved renovating using cases when the replacement building would be twice the size. They believe this assumption is conservative.

ECONorthwest calculates that renovating a 1,500 SF historic home reduces embodied CO_2 emissions by 126 tons valued at $2,723 over tearing it down and replacing it with a 3,000 SF residential building. The savings is equal to a 44,048 gallon reduction in gasoline use.[2] In the situation of a 10,000 SF commercial building the CO_2 emissions savings would be 1,383 tons valued at $29,923. That savings is equivalent to 484,127 fewer gallons of gasoline use. The average car uses 474 gallons a year.[3] Thus, a house renovation equals taking 93 cars off the road; commercial buildings 1,028 cars off the road.

Table 2: Metric Tons and Dollar Value of CO_2 Emissions Reductions for Two Example Situations

Example Situation	Metric Tons of CO2 Emissions	Value, 2020 $	Equivalent Gallons of Gasoline
1,500 SF house:			
Replace with a 3,000 SF house	136		
Renovate	10		
Net CO2 reduction	126	$2,723	44,048
10,000 SF Commercial Building:			
Replace with a 20,000 SF building	1,451		
Renovate	68		
Net CO2 reduction	1,383	$29,923	484,127

Research Considered

ECONorthwest sought useable research from academic, construction and engineering, economic, government, and scientific literature. We spoke to energy experts. We found that the avoided impacts of embodied energy from renovating over rebuilding has not been a focus of most research.

There is a consensus that renovating results in lower embodied CO_2 emissions that tearing down and building new. However, the vast majority of construction decisions do not involve a trade-off between historic preservation and replacement. Further, over a 100-year lifespan, operational energy far exceeds embodied, so research focuses on operational energy.

The following are short summaries of the research ECONorthwest used in its analysis.

Adlerstein, Michael, Vidaris, Inc., Syska Hennessy Group. "Assessing the Carbon-Saving Value of Retrofitting versus Demolition and New Construction at the United Nations Headquarters." New York, NY: The United Nations Capital Master Plan, 2016.

The United Nations began a large-scale renovation of its New York headquarters campus in 2007 - the first since its construction in the 1950s. Much consideration was given to the historical, architectural, and cultural significance of preserving the building versus demolishing. Environmental benefits were much more difficult to quantify and "often unaccounted for in municipal, state, or

[2] Based on 6.3 pound of carbon dioxide produced by burning one gallon of gasoline. Source: https://www.fueleconomy.gov/feg/contentIncludes/co2_inc.htm

[3] "Monthly Energy Review." U.S. Energy Information Service. April 2020. Page 21.

national carbon reduction plans and projections" (Adlerstein 20). Further investigation found significant value in extending the life of the building indicating the improvements in operational energy efficiency would not offset the loss of the invested embodied energy.

The study concluded that,

- "If the UN complex had been demolished and replaced with new construction of similar size, it would have taken between **35 – 70 years** before the improved operating efficiencies of the new complex would have offset the initial outlays of carbon emissions associated with the demolition and new construction process" (Adlerstein 2).

Strain, Larry. "Time Value of Carbon." Seattle, WA: Report prepared for Carbon Leadership Forum at the University of Washington, 2017.

This paper discusses ways to reduce emissions in the built environment with a focus on embodied emissions over operational. The paper used data from over 1,000 actual construction projects covering a wide range of building types and geography where renovation was compared to demolition and replace. The estimates were based off of known, standard construction engineering models used in the U.S.

The paper emphasized the opportunity to have a more immediate impact on carbon reduction by reusing buildings.

- "Embodied emissions are also important because of when they occur – they are the first emissions from a new building. When a building is constructed - before it starts operating and generating operating emissions - it is already responsible for tons of GHG (greenhouse gas emissions). And even though the majority of embodied emissions happen once -- when the building is constructed -- and operating emissions happen over time and are cumulative, the majority of GHG emissions for the first 15 – 20 years of a building's life will be the embodied emissions from materials and construction" (3).
- "Building renovations generate significantly lower emissions than new construction, typically 50 – 75% less than new buildings generate" (6)
- "Over a building's lifespan, typically 75 – 100 years, embodied emissions only accounted for 10% - 20% of a building's total emissions" (2)

ULI Greenprint Center for Building Performance. "Embodied Carbon in Building Materials for Real Estate." Washington, DC: Urban Land Institute Americas, 2019.

Buildings are significant contributors to carbon emissions. This article suggests preemptively implementing the use of low-embodied carbon design practices and materials to prepare for coming industry changes, especially as discussions about regulations gain traction. The authors provide key strategies and low-cost wins to reduce embodied carbon while recognizing the inherent challenges. One key strategy is to redevelop and reuse buildings:

- "Structural systems can comprise up to 80 percent of a building's embodied carbon, depending on building type, so the most significant factor in a building's embodied carbon is whether the development uses an existing building or constructs a new one. Large quantities of steel and concrete are most frequently used in the structure of new buildings, so by taking advantage of existing infrastructure via redevelopment of existing assets, projects can avoid spending on raw materials and significantly decrease embodied carbon" (ULI 15).

Interagency Working Group on Social Cost of Carbon, United States Government. "Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866." Washington, DC: GPO, 2010.

- "The purpose of the "social cost of carbon" (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions" (GPO 1).
- The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change " (GPO 1).

Berkeley Economic Advising and Research. "Oregon's Cap-and-Trade Program (HB 2020): An Economic Assessment." 2019

- A consulting study produced for the Oregon Legislative Revenue Office outlining the economics of cap-and-trade legislation. The report is available at https://olis.leg.state.or.us/liz/2019R1/Downloads/CommitteeMeetingDocument/159628

This project was funded in part by:

Oregon Heritage – State Historic Preservation Office

A grant from the Pacific Northwest Heritage Fund of the National Trust for Historic Preservation