Denver's Building Sector Embodied Carbon Emissions

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DENVER
CLIMATE ACTION, SUSTAINABILITY & RESILIENCY

lotus
engineering & sustainability

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ABBREVIATIONS & TERMINOLOGY

Buildings – All Commercial Buildings (commercial, industrial, multifamily).
CLF – Carbon Leadership Forum.
CASR – Denver's Office of Climate Action, Sustainability, and Resiliency.
EUI – Energy Use Intensity.
EPD – Environmental Production Declaration.
FSC - Forest Stewardship Council.
GHG – Greenhouse Gas.
Homes – All Single-family Dwellings (attached and detached).
IECC – International Energy Conservation Code.
LCA – Life-cycle Assessment.
MFU – Multi-family Units.
Natural gas – Gas.
NZE – Net Zero Energy.

INTRODUCTION & SUMMARY

As Denver works to reduce operational emissions in buildings over time, the importance of embodied carbon grows. The City and County of Denver (Denver) contracted with Lotus Engineering and Sustainability, LLC (Lotus) to analyze Denver's building sector embodied carbon emissions. This analysis will inform the City's thinking on the value of embodied carbon policies. The hope is to also inform decisions made by Denver's architects, developers, and other stakeholders as they build buildings and homes in Denver and as they participate in Denver's code adoption process.

Based on the key findings, there are key recommendations for Denver as it considers widening building policies to address both operational and embodied carbon emissions. Denver can prevent embodied carbon emissions by using salvaged building materials. Embodied carbon can be reduced and optimized by adapting to different materials and specifications. Buildings can plan for embodied caron emissions through building deconstruction techniques and end of life use. Policy development can create regulations and develop accountability measures to protect the environment such as, prioritizing embodied carbon building policies that address the commercial sector.

The Significance of Embodied Carbon in Denver

The study of embodied carbon in Denver buildings will help to develop policies and inform decisions made by Denver's architects, developers, and stakeholders.

A building's life cycle GHG emissions are comprised of operational carbon and embodied carbon. Operational carbon emissions results from the on-site electricity and natural gas (gas) consumption required to operate buildings and homes. Embodied carbon is generated from the materials used to build structures and includes material extraction, manufacturing, transportation, building construction, maintenance, demolition or deconstruction, and disposal. Refer to Figure 1.

As Denver achieves the goal of all *new* buildings and homes meeting net zero energy by 2030, the operational carbon emissions will significantly decline. By 2040, when Denver meets its goal for *all* buildings and homes achieving net-zero by 2040, operational carbon emissions will disappear, and embodied carbon will become 100% of the emissions.

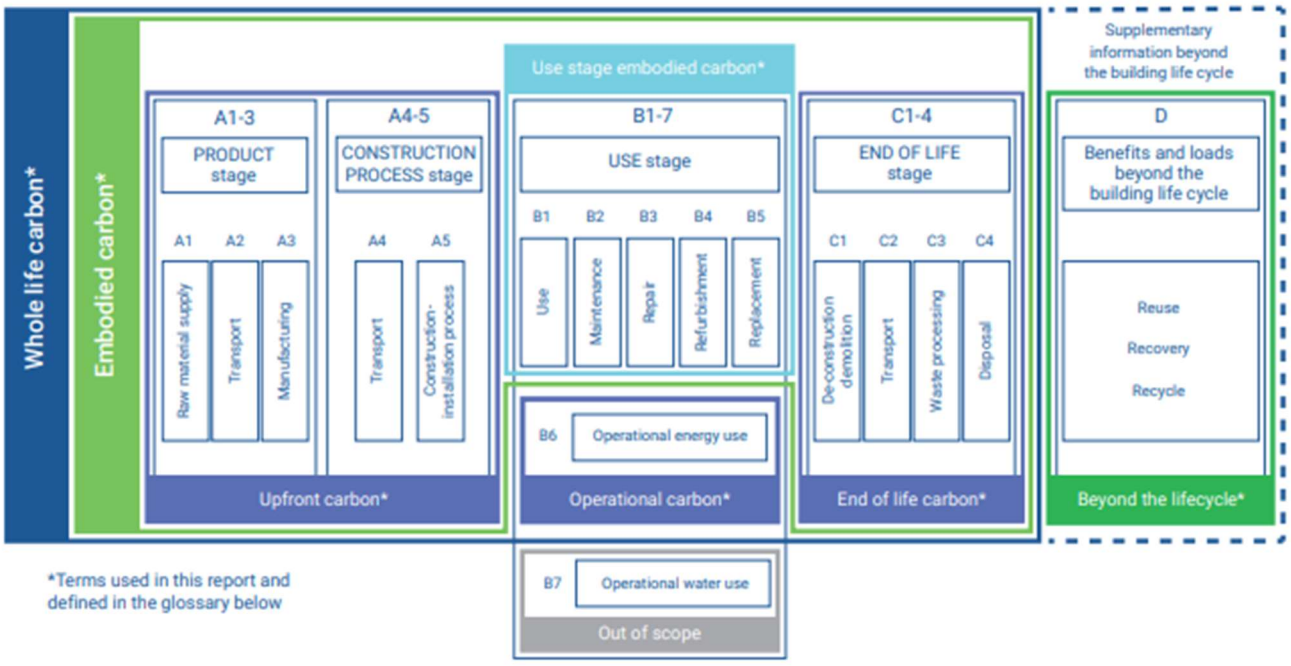


Figure 1. Life cycle stages of a typical building.[i]

KEY FINDINGS

The first step of the analysis for Denver included quantifying emissions of both the operational carbon and embodied carbon. Most importantly, it also compared the two in order for Denver to understand how best to reach Denver's climate goals by understanding if the emissions are operational or embodied and how this changes over time.

Comparing Operational to Embodied Carbon Emissions

The significance of embodied carbon grows over time as Denver's climate goals to reduce operational emissions through net zero energy (NZE) are achieved for both new and existing buildings. In 2020, operational carbon emissions far outweigh emissions from embodied carbon. In 2030, embodied carbon emissions will make up 27 percent of all emissions from buildings built in 2030 compared to annual operational emissions for all buildings in 2030. By 2040, both existing and new buildings will be NZE, so 100% of emissions will be from embodied carbon. As we meet Denver's goals, the operational emissions disappear, and the embodied carbon becomes 100% of the emissions. Refer to Figure 2.

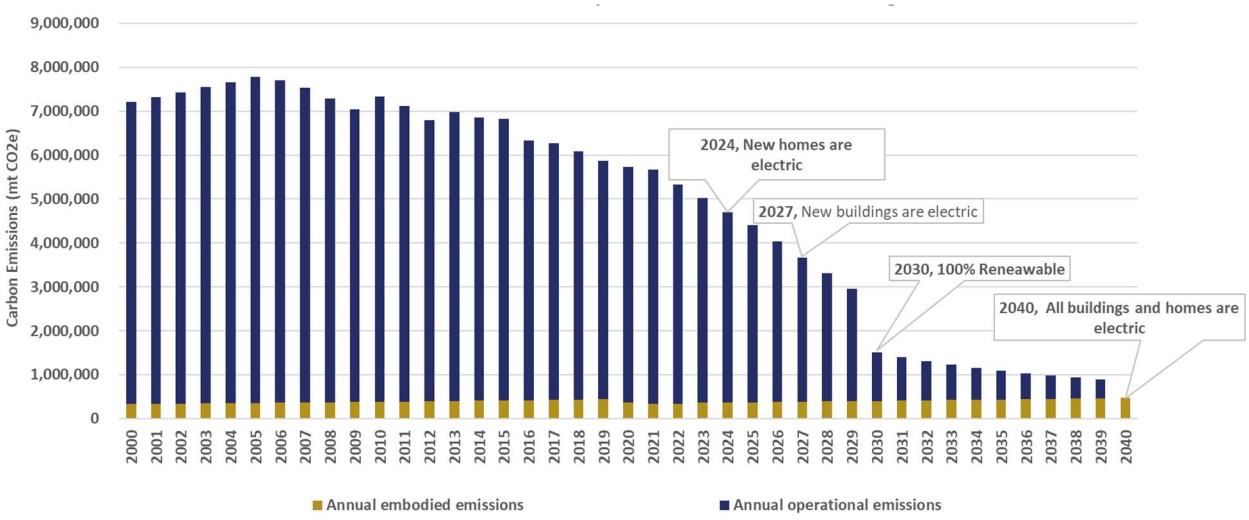


Figure 2. Embodied carbon and operational emissions for all buildings by year.

Comparing Embodied to Lifetime Operational Emissions

The effects of Denver's net zero code impacts, building electrification, and renewable energy goals shift the emphasis towards embodied carbon emissions over time. The ratio shrinks with every year that Denver improves building performance requirements. By 2030, 100% of emissions for buildings constructed that year will be embodied carbon emissions. The 2030 milestone is approaching, so the significance of addressing embodied carbon increases every year. Refer to Figure 3. Denver needs to account for the embodied carbon emissions as policies are built to protect people and the environment.

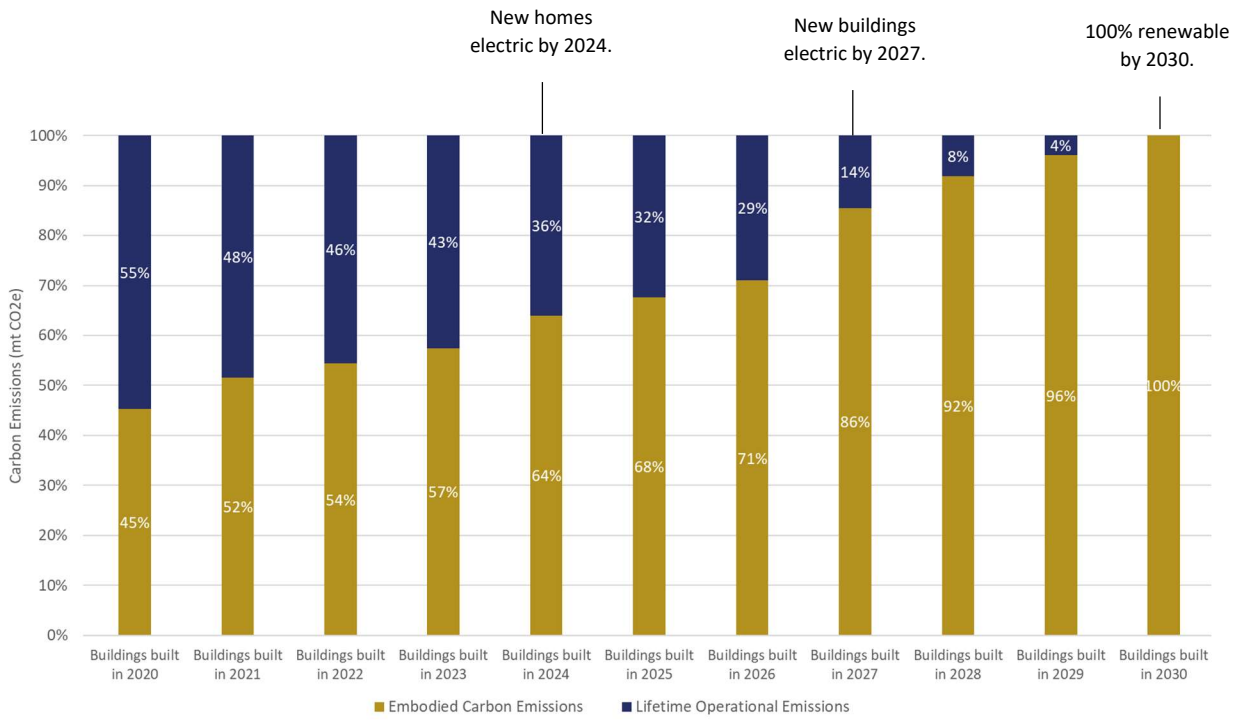
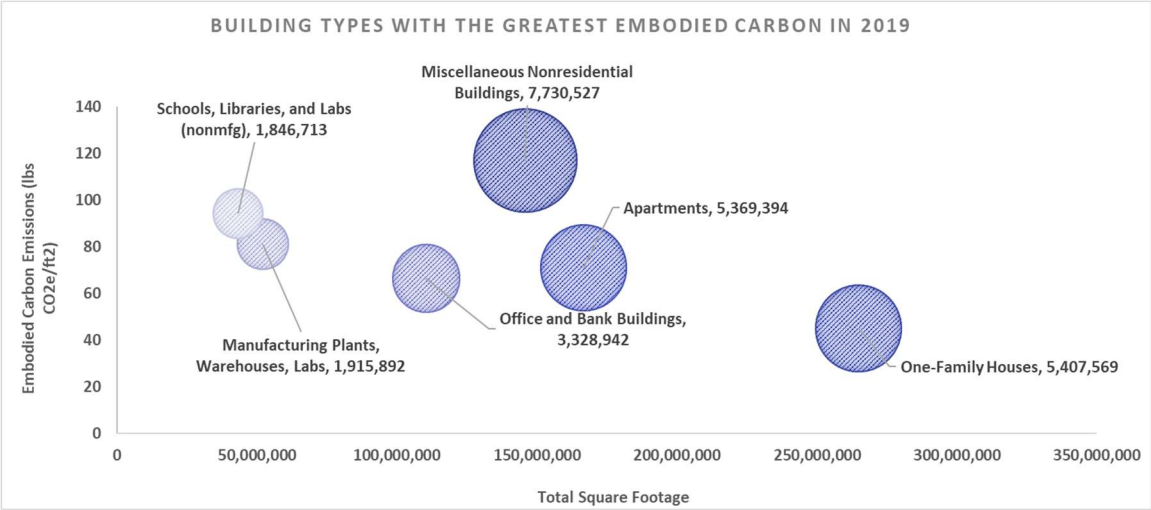


Figure 3. Comparison of embodied to lifetime operational emissions for buildings built between 2020 and 2030.

EMBODIED CARBON EMISSIONS BY BUILDING TYPE & SECTOR

Some building types have higher embodied carbon by having a high embodied carbon emission factor or by having a large building footprint area. Both effects should be considered when addressing embodied carbon by building type. When combined (i.e., the product of square footage and embodied carbon emission factors), the building types that produce the most embodied carbon are represented by the largest and darkest circles in Figure 4.

Other nonresidential buildings have the most embodied carbon since they have the largest building area footprint and the highest carbon emission factor. Single-family homes have a large building area footprint but a low emission factor, so the high emissions result from the sheer number of homes. Building types with the largest embodied carbon emissions should be prioritized for policies that reduce embodied carbon.



- ***Figure 4. Ranking of embodied carbon emissions by building type in 2019.***

Most of Denver's embodied carbon emissions are produced by the commercial sector, which includes commercial, industrial, and multifamily buildings. Understanding that commercial buildings have the highest impact can help when developing strategies and policies for targeting embodied carbon emissions.

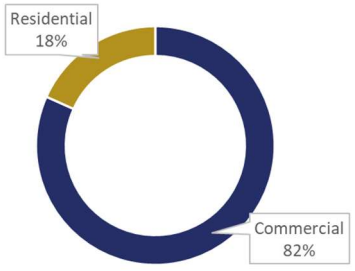


Figure 5. 2019 Commercial to residential embodied carbon.

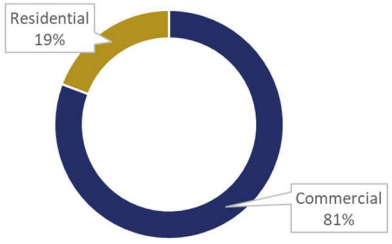


Figure 6. 2040 Commercial to residential embodied carbon.

Sources of Embodied Carbon

"Upfront carbon," the emissions generated before the building is used, are estimated to be responsible for between 50 and 80 percent of all emissions from new construction by 2050. Upfront carbon, contributes the most to a building's embodied carbon emission total, and these sources have the greatest opportunity to be reduced, refer to Figure 7[ii].

- Foundation: footings and retaining walls.
- Structure: framing, reinforcement, slabs, and decking.
- Enclosure: cladding, fenestration, insulation, and roofing.
- Additional assemblies: interior furnishings (equipment, fixtures, furniture), building systems (electrical, mechanical, and plumbing), and site work (excavation, exterior paving, and shoring and formwork).

Most emissions are generated from the production of the following structural elements:

- Concrete
- Steel
- Wood

The second-largest source of embodied carbon in buildings is from the building's enclosures.

Some life-cycle assessment (LCA) studies [1] suggest that aluminum curtainwall and foam insulation are the greatest enclosure contributors to carbon.

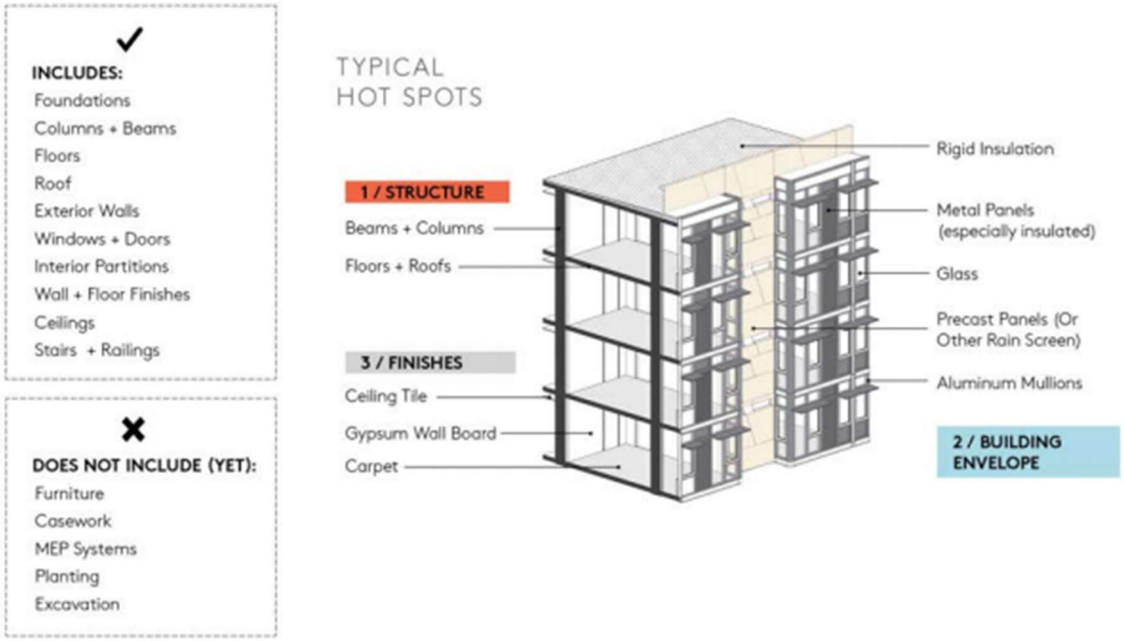


Figure 7. Typical hot spots of a building's embodied carbon.

[1] See The Urgency of Embodied Carbon and What You Can Do About It and Building Green

RECOMMENDATIONS

Embodied Carbon Emissions by Material Type

Using low-embodied carbon emission material types has the potential to reduce embodied carbon emissions by up to 60 percent in an example home, see Figure 8.

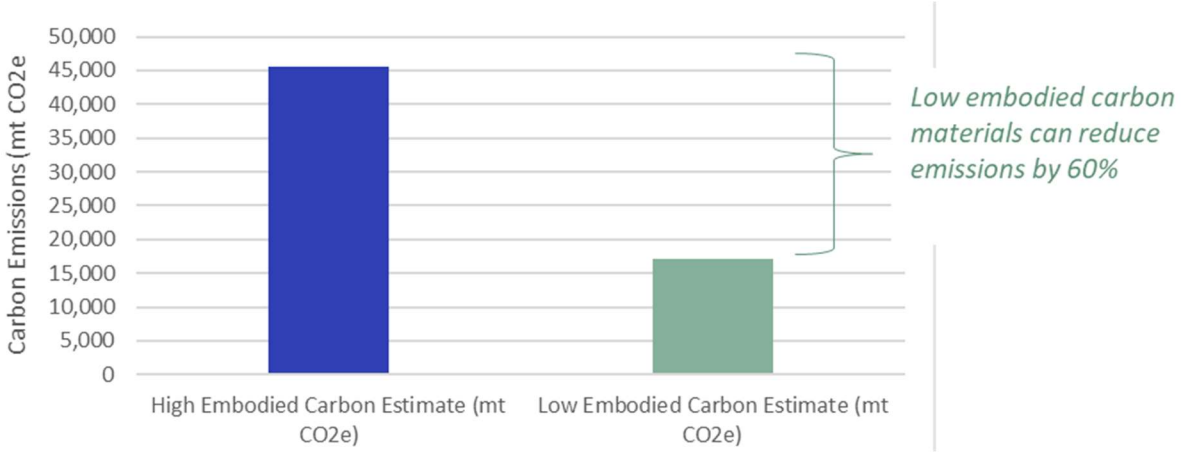


Figure 8. Embodied carbon emissions from different material types in example home.

Biggest Opportunities to Reduce Embodied Carbon

Based on the key findings comparing embodied carbon to operational carbon, emissions by building type and sector, and emissions from material type, embodied carbon increasingly impacts the health of our environment. There are steps Denver can take to reduce the embodied carbon emissions on the planet. The following set of best practices may be used by Denver as it considers widening building policies to address both operational and embodied carbon emissions.

- **Prevent.**
  - Reuse and repurpose existing buildings – establish an adaptative reuse policy.
  - Use salvaged building materials in new construction.
  - Consider adaptive reuse during initial design to ensure that buildings can be used for different purposes over their lifetime.
- **Reduce and optimize.**
  - Understand which materials contribute the most; limit their use.
  - Require transparent product documentation such as environmental product declarations (EPDs) to help decide which low-carbon materials to use.
  - Limit the use of and replace materials with the most embodied carbon.
  - Involve the structural engineers from the onset. The greatest amount of embodied carbon is emitted from the building's structural system – concrete, steel, or wood. Ensure composite design using concrete and steel are prioritized.

- Denver should require concrete containing supplemental cementitious materials like fly ash or blast-furnace slag in place of Portland cement to be included in construction specifications.
- Avoid over-engineering building designs to reduce use of concrete, wood, and steel.
- If using steel, use steel sourced from North America, which typically has a lower carbon footprint than steel manufactured overseas. Pueblo, CO plans to have the world's first solar-powered steel mill. This factory will create jobs in the local economy, while lowering the carbon emissions impact.
- Require at least 50% recycled steel content in construction specifications.
- Use Forest Stewardship Council (FSC) certified wood and salvaged wood.
- Minimize aluminum curtainwalls.
- Use alternatives to foam insulations types that have high global warming potentials.
- Consider sourcing materials that meet steel and concrete low-embodied carbon guidelines: ResponsibleSteel and Concrete Sustainability Council.

- **Plan.**
  - Consider the end-of-life use – provide salvaged materials to another project or reuse building.
  - Design for Deconstruction – Design building assemblies to make building materials more easily salvageable.

Recommendations for Policy Development

Best practices will certainly make an impact, and policy development can create regulations and develop accountability measures to protect the environment. Integrate best practices[2] into policy design and further consider:

- Prioritizing building and home types with the greatest embodied carbon emission factors and most square footage when developing embodied carbon policies as well as those that contribute the most emissions to Denver's building stock.
- Prioritizing embodied carbon building policies that address the commercial sector.
- From an annual operational carbon perspective, developing embodied carbon emission policies that affect building practices when operational emissions start to decline – in the latter half of the 2020s but no later than 2030.
- From a lifetime operational carbon perspective, developing embodied carbon emission policies that affect building practices when operational emissions become less dominant, in 2021.
- Encouraging or mandating low-embodied carbon material types.
- Providing incentives or requirements for the use of low-carbon construction materials.
- Encouraging adaptive reuse policies for existing buildings to avoid additional embodied carbon emissions.
- Facilitating the development of construction material recycling and reuse programs, facilities, and networks.
- Developing a net-zero embodied carbon building policy, including:
    - Zoning for more multi-unit dwellings.
    - Removing minimum home size restrictions to allow for smaller dwellings.
- Including embodied carbon goals in building codes.
- Requiring building specs to include materials with a minimum percentage recycled content.
- Developing the building code to accommodate low embodied carbon building materials such as rammed earth or adobe block.

[2] Includes guidance from the USDN Sustainable Consumption Toolkit.

APPENDIX A – CALCULATION METHODOLOGY

How Denver's Embodied Carbon is Measured

We analyzed embodied carbon emissions by building type and by material type. Our analysis shows:

- Which building types produce the most embodied carbon.
- How emissions change over time.
- A comparison between embodied and operational emissions.
- Which materials should be used to lower embodied carbon footprints.

Emissions by Building Type

The following outlines our approach to estimating embodied carbon emissions from both existing and new buildings. Detailed calculations can be referenced in the accompanying spreadsheet.

1. **Identified existing and new building square footage**.
    a. Denver provided new construction square footage data from a Dodge Data dataset. We used this dataset to determine:
        i. Main building types. To stay consistent with Denver's building policies, we included multi-family (MFU) (i.e., Dodge Data's "apartments") with the commercial sector; the residential sector only included Dodge Data's categories of one-family houses (i.e., single-family homes) and two-family houses.
        ii. Additional square footage is built each year from 2019 until 2023 per building type.
        iii. Average annual growth per building type, where a negative value indicates that there are fewer square feet of new buildings being added each year.
    b. After 2023, we assumed a 1.5 percent growth every year based on predictions from Denver's Assessor.
    c. We determined the total existing building stock data in two ways. Commercial sector square footage was taken from the 2019 GHG inventory. Residential square footage was taken from Denver's Open Data Catalog. The total square footage equaled the sum of a finished basement, garden level, and above grade areas. Denver Open Data Catalog showed that duplexes and triplexes represented less than 0.001 percent of the total residential square footage.
    d. Existing square footage data was not available by building type. Therefore, we assumed the percent of existing square footage per building type using Energize Denver's benchmarking dataset. We applied this distribution to the total square footage to estimate the existing square footage of buildings per type.

Sector	Dodge dataset building types	Percent of total based on SF	2019 Square Footage
Commercial	Amusement, Social and Recreational Bldgs	2%	15,210,338
	Dormitories	1%	5,456,090
	Government Service Buildings	1%	3,162,937
	Hospitals and Other Health Treatment	2%	10,440,476
	Hotels and Motels	5%	28,070,463
	Manufacturing Plants, Warehouses, Labs	8%	52,077,439
	Miscellaneous Nonresidential Buildings	23%	145,754,765
	Office and Bank Buildings	18%	110,390,419
	Parking Garages and Automotive Services	0.4%	2,788,246
	Religious Buildings	1%	3,824,169
	Schools, Libraries, and Labs (nonmfg)	7%	43,156,795
	Stores and Restaurants	1%	5,135,227
	Warehouses (excl. manufacturer owned)	5%	29,807,714
Multifamily	Apartments	27%	166,655,585
	Total square footage	**100%**	**621,930,664**
Residential	Single Family	99.999%	264,818,339
	Other	0.001%	2,648
	Total square footage	**100%**	**264,820,987**

Figure 9. Building type distribution by square feet.

e. Annual totals of square footage per building type were calculated by summing the square footage of existing building stock with Dodge Data's projections of square footage.

2. **Retrieved embodied carbon emission factors**. Using CLF's Embodied Carbon Benchmark Research, we captured embodied carbon emission factors per square footage for different building types.
3. **Aligned Dodge Data building types with CLF's building types**. The building type definitions differed between CLF and Dodge Data's datasets. We aligned the building types and assigned the emission factors to each. See Figure 10.

Sector	CLF Building Type	Dodge Data Building Type	Embodied Carbon Emissions (mt CO_2e / $m^{2)}$	Embodied Carbon Emissions (mt CO_2e / ft^2)
Commercial	Education	Schools, Libraries, and Labs (nomfg)	0.4606	0.0428
	Health Care	Hospitals and Other Health Treatment	0.5116	0.0475
	Lodging	Dormitories, Hotels and Motels	0.3525	0.0327
	Mercantile	Stores and Restaurants	0.4788	0.0445
	Mixed Use	Amusement, Social and Recreational Bldgs	0.4698	0.0436
	Office	Government Service Buildings, Office and Bank Buildings	0.3246	0.0302
	Other	Miscellaneous Nonresidential Buildings	0.5709	0.0530
	Parking	Parking Garages and Autmotive Services	0.3402	0.0316
	Public Assembly	Religious Buildings	0.5224	0.0485
	Warehouse	Warehouses (excl manufacturer owned), Manufacturing Plans, Warehouses, Labs	0.396	0.0368
	Multifamily	Apartments	0.3468	0.0322
Residential	Single Family	One-Family Houses	0.2198	0.0204
	Other	Two-Family Houses	0.2343	0.0218

Figure 2. Embodied carbon emission factors by building type.

4. **Calculated embodied carbon emissions by building type**. We multiplied Denver's square footage from each building type by the embodied carbon emission factor for that building type to show embodied carbon by building type and total and annual increases in embodied carbon.

5. **Calculated annual and lifetime (i.e., cumulative) embodied carbon emissions for existing and new buildings and homes**. To better understand the comparison between operational and embodied carbon, we separated embodied carbon from existing and new buildings.
    a. Embodied carbon emissions from existing buildings assumed the following:
        i. Embodied carbon emissions grew at the rate of square footage growth.
        ii. Operational emissions from 2005 until 2019 were taken from Denver's GHG emission inventories. Operational emissions before 2005 were estimated assuming that:
            a. Natural gas emissions and electricity consumption decreased by the average annual building stock growth rate of 1.5 percent (Denver provided the assumed increase in overall building stock growth).
            b. The 2005 emission factor remained constant. The back casted operational emissions were the sum of the estimated natural gas and electricity emissions.
    b. Embodied carbon emissions from new buildings considered the following:
        i. Operational emissions past 2020 were calculated assuming:
            a. Xcel's emission factors gradually decreased until their GHG emission targets were reached in 2030 and 2050.
            b. Denver will be 100 percent renewable by 2030.
            c. New builds in 2020 follow the 2018 International Energy Conservation Code (IECC), new builds in 2021 through 2024 follow the 2021 IECC, and new builds in 2024 through 2025 follow the 2024 IECC.
            d. Per Denver's net zero energy goals[3]: all new homes will be all electric by 2024 and all new buildings will be all electric by 2027.
            e. Per Denver's Climate Action Task Force goals[4]: all existing buildings and homes will be all electric by 2040, with a linear increase in adoption of 7 percent starting in 2026.
            f. Per projections provided to Denver's Energize Denver Task Force, Denver's buildings will see an incremental increase in efficiency of 3 percent each year between 2026 and 2031.
            g. The 2021 IECC will require an energy use index (EUI) value of 10 percent less than the 2018 IECC[iii], and each subsequent IECC will be 10 percent more efficient than the previous IECC.
            h. Residential and commercial EUI values for the 2018 and 2021 IECC were assumed based on recent research from the Pacific National Laboratories and the Department of Energy.
            i. Climate Zone 5 was used.
            j. Buildings' and homes' total energy consumption is approximately 50 percent natural gas and 50 electricity.

[3] For more information visit Denver's Net Zero New Buildings & Homes website.

[4] For more information see Denver's Climate Action 2020 Recommendations Report.

DENVER'S BUILDING STOCK

As Denver's building stock grows, more embodied carbon emissions will be created. Metro Denver has a population of more than 3 million.[iv] The region grew steadily in the past 10 years, and by 2030, Metro Denver's population is anticipated to reach more than 3.6 million.[v] This growth leads to more home and building construction. Denver completed an analysis with Dodge Data and Analytics data (Dodge Data) on projected new construction from 2014 to 2023 (see Figure 11). [vi] This dataset suggests that embodied carbon emissions have oscillated between 2014 and 2019 and will continue to change at different rates until 2023, but generally, embodied carbon emissions are expected to increase compared to the 2014 value.

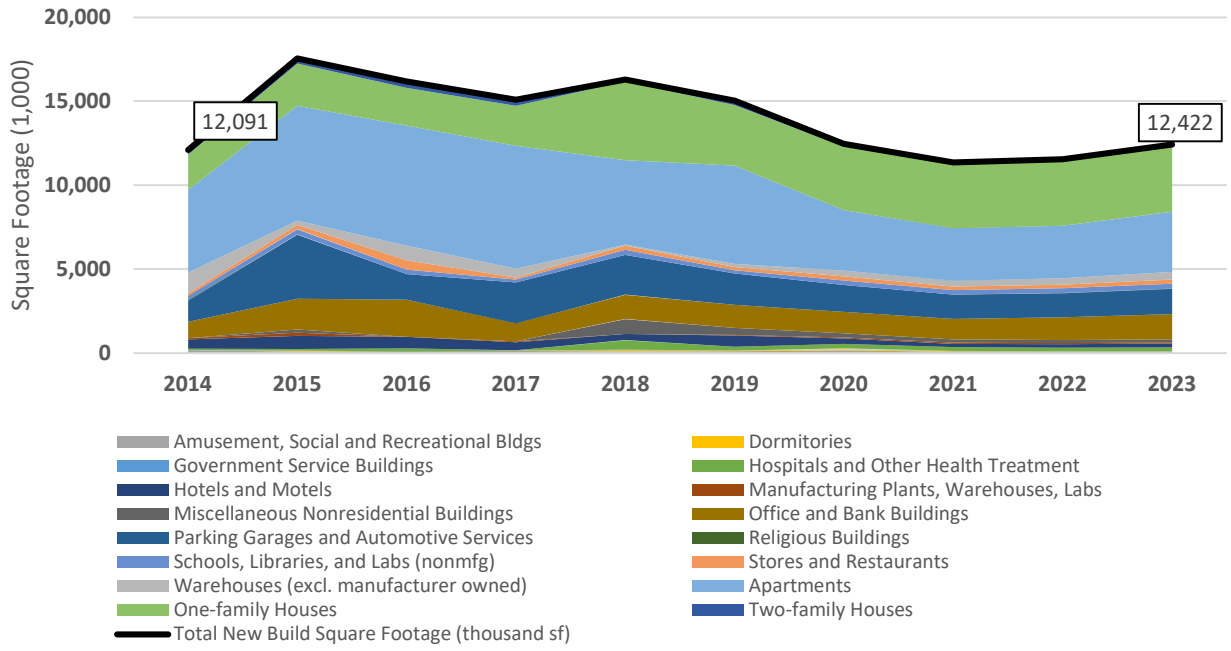


Figure 11. Expected square footage growth per building type. [vii]

Denver's Assessor's data predicts that square footage will increase at a conservative rate of 1.5 percent per year after 2023 based on historic patterns between 1997 and 2016.[viii]

While Denver expects operational emissions to decrease over time, embodied carbon emissions are likely to grow if there is no intervention. Unlike operational emissions, embodied carbon emissions are "irreversible" and are emitted once a building's materials are made and the building is constructed. Even in the case of net zero energy new construction, the construction materials themselves have contributed such high emissions in their extraction and refining, that the building is essentially emitting for decades, see Figure 12.

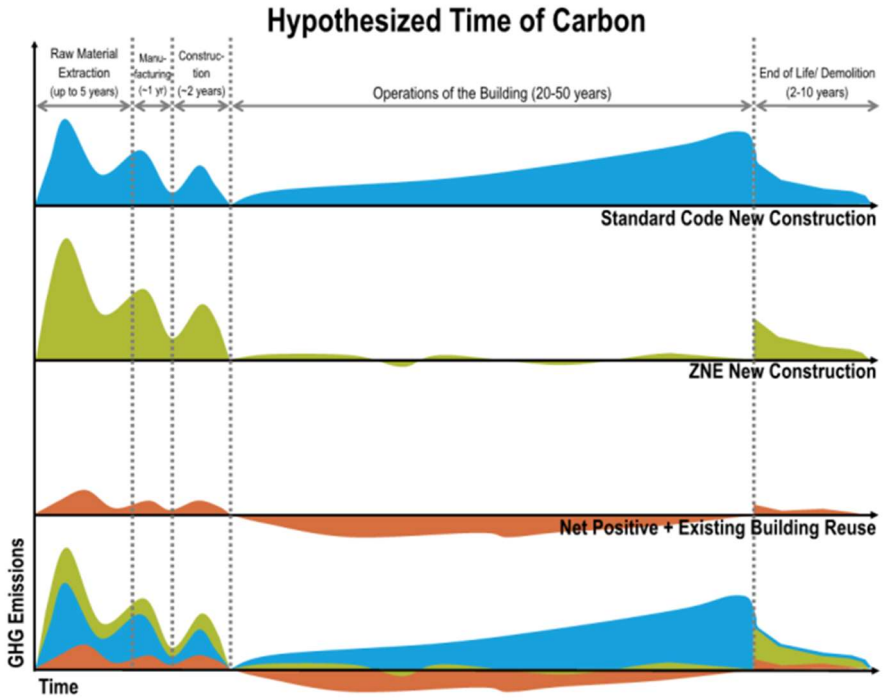


Figure 12: Hypothesized Time of Carbon.[ix]

Recognizing the impact this has on the global building sector emissions, green building experts are now encouraging practices that reduce embodied carbon, primarily in the early planning phases.

Emissions by Material Type

The following outlines our approach to estimating embodied carbon emissions from low- and high-embodied carbon materials. Detailed calculations can be referenced in the accompanying spreadsheet.

1. **Defined seven common building materials used in construction**: Material inputs included material types, material specifications, and unit of material used. Concrete, Rebar, Framing, Sheathing, Insulation, Gypsum board, and Carpet. These were based on the available data in the CLF's Embodied Carbon in Construction Calculator Tool. See Table 2.

Table 1. Carbon emissions by material type.

Material	Amount of material needed for 2019 home size	Unit of Material	Standard Embodied Carbon Estimate (kg CO_2e)	Standard Embodied Carbon Estimate (mt CO_2e)	Low-carbon Embodied Carbon Estimate (kg CO_2e)	Low-carbon Embodied Carbon Estimate (mt CO_2e)
Concrete	10.79	1 yd3	4,370.28	4.37	2,244.49	2.24
Rebar	20,285.62	1 lb.	12,779.94	12.78	6,349.40	6.35
Framing	235.43	1 yd3	13,725.64	13.73	5,509.09	5.51
Sheathing	42.54	1 yd3	10,592.40	10.59	5,189.85	5.19
Insulation	3,216.15	1 ft2	9,005.21	9.01	749.36	0.75
Gypsum Board	3.37	1000 ft2	1,704.46	1.70	784.86	0.78
Carpet	2,384.00	1 ft2	3,599.85	3.60	1,995.41	2.00
Total Embodied Carbon			55,777.78	55.78	22,822.46	22.82
Difference between low- and standard embodied carbon houses						59%

2. **The defined average size of a residential single-family house in the US**. According to the US EPA, the average size of a single-family residential house in the US in 2019 was 2,301 square feet.
3. **Collected high- and low-end estimates of embodied carbon emission factors for each material in CLF's Embodied Carbon in Construction Calculator Tool**. The low-end estimate is called "achievable" and the high-end estimate is called "conservative" in the Tool.
4. **Researched the average amount of the seven materials used in a typical residential house.** These values were converted to the average value per square foot of house for ease of calculations.
    a. Calculated high- and low-end estimates of embodied carbon in an average US residential house.

General Embodied Carbon Calculation Approaches

Embodied carbon emission factors (also referred to as carbon intensity) are a component of a life-cycle assessment (LCA) calculation, which is commonly based on calculation methodologies from ISO 14040 and ISO 14044[x]. Embodied carbon emission factors typically provide an estimate of carbon generated per weight of the material. Unfortunately, it is difficult to compare different material weights (i.e., the weight of wood needed to construct a building versus the weight of steel) for all buildings. Therefore, many embodied carbon analyses use environmental production declarations (EPDs) in place of standard emission factors. While EPDs are not always calculated consistently and some building experts caution using EPDs, EPDs are accompanied by transparent calculation documentation, and their use is frequently cited as the most objective way to compare products and select low-carbon materials. EPDs are used to compare a baseline or status-quo product or combination of products (i.e., an assortment of building materials or a building) against an alternative low-carbon scenario.

Several free and fee-for-service EPDs databases have been developed, including:

- mindful MATERIALS.
- The International EPD System.
- Sustainable Minds.
- UL SPOT.
- CLF's Embodied Carbon in Construction Calculator tool.

The International Living Future Institute, a nonprofit designed to help buildings achieve zero embodied carbon certifications, has approved all of the databases listed above.

Ideally, embodied carbon emissions would be estimated using a detailed building LCA. This analysis requires software modeling and is beyond the scope of this effort. Life-cycle analyses are complicated, rely on a variety of inputs from different sources (that do not always align), and are best used to examine emissions from a particular building or structure rather than an entire community. The International Living Future Institute approved the following tools to complete LCA analyses:

- Athena Impact Estimator.
- Environment Agency's Carbon Calculator.
- eTool.
- One-Click LCA.
- Tally.

LIMITATION OF ANALYSIS

While the practice of quantifying emissions through an LCA has been around for a decade or more, the practical application of LCA findings and embodied carbon emissions has not been widely adopted, and is, therefore, relatively new. This produces extensive limitations.

Varying perspectives on embodied carbon contributions. The Concrete Sustainability Hub of Massachusetts Institute of Technology wrote, "The operational phase of a building, however, makes the largest contribution to the life cycle impacts of a structure and can overshadow the embodied emissions."[xi] And "When the GWP [Global Warming Potential] for the total life cycle is calculated, it becomes clear that the embodied emissions are a small fraction of the life cycle emissions..." [xii] While the World Green Building Council[xiii], the International Living Future Institute[xiv], and Building Green[xv] note that operational and embodied emissions may contribute equally to a building's overall emissions today, [xvi] embodied carbon emissions are expected to be more significant over the next several years and may represent up to 90 percent of a building's total emissions by 2050[xvii]. The baseline assumptions (i.e., grid makeup, etc.) from which each organization builds its calculations heavily influence the role of embodied carbon contributions.

Varying data inputs and complicated calculation methodologies. Because of the wide range of data inputs and the seemingly new calculation approach, LCA and embodied carbon emissions are complicated to calculate. Many calculations rely on proprietary software calculation tools and embodied carbon emissions are the sum of individual metrics, such as EPDs. Plus, since the calculation methodology requires a reference and alternative state, it can be difficult to accurately complete these calculations on a large scale.

> *"The more we've dug, the more [the numbers] seem to be all over the place. There is so much uncertainty carried with them." Regarding uncertainty when comparing embodied carbon emissions of wood to steel and concrete. -- Frances Yang with Arup*

Emerging field with no standard guidance. Embodied carbon emission factors vary among sources. The Massachusetts Institute of Technology's *Methods, Impacts, and Opportunities in the Concrete Building Life Cycle* states "The life cycle assessment of buildings is now a well-established field and yet there is still no internationally agreed-upon standard for building LCAs." LCAs form the basis for embodied carbon emission factor methodologies.

Definitions can vary. Even the definition of embodied carbon can vary. Some include a building's operational emissions, while the majority do not.

Based on the data available and the scope of our analysis, we recommend estimating embodied carbon emissions on a building type basis using CLF's emission factors per building type and by looking at the impacts of choosing low- and high-embodied carbon materials in a new build.

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[i] For more information see: https://journal-buildingscities.org/articles/10.5334/bc.31/.
[ii] For more information see https://buildingtransparency-live-87c7ea3ad4714-809eeaa.divio-media.com/filer_public/32/d5/32d56e02-4513-4357-ab65-f3cd364e2c10/wc_am-materialscanspotlightecbuildinggreen2020.pdf.
[iii] For more information see: https://newbuildings.org/code_policy/2021-iecc-base-codes/.
[iv] Refer to U.S. American Factfinder.
[v] http://www.metrodenver.org/do-business/demographics/population/#:~:text=Metro%20Denver%20has%20a%20population,to%20more%20than%203.6%20million
[vi] Analytics, D. D. (2019). Dodge_DenverCntyConstrStarts_19Q2_withPercentChng.
[vii] Analytics, D. D. (2019). Dodge_DenverCntyConstrStarts_19Q2_withPercentChng.
[viii] For more information refer to Denver's spreadsheet *Building Stock Growth, 1.5%, 8-1-19.*
[ix] Ecological Building Network. (2015). The Total Carbon Study. Retrieved from https://www.ecobuildnetwork.org/images/pdfs/The_Total_Carbon_Study_FINAL_White_Paper_published_20151113.pdf and
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[x] For more information see https://www.iso.org/standard/37456.html.
[xi] For more information see https://dspace.mit.edu/handle/1721.1/105108.
[xii] Ibid.
[xiii] For more information see https://www.worldgbc.org/news-media/bringing-embodied-carbon-upfront.
[xiv] For more information see https://trimtab.living-future.org/embodied-carbon/embodied-carbon-guidance-what-is-it-and-why-do-we-need-it/.

[xv] For more information see https://www.buildinggreen.com/feature/urgency-embodied-carbon-and-what-you-can-do-about-it.
[xvi] For more information see https://www.buildingtransparency.org/en/materialscan/.
[xvii]For more information see https://buildingtransparency-live-87c7ea3ad4714-809eeaa.divio-media.com/filer_public/32/d5/32d56e02-4513-4357-ab65-f3cd364e2c10/wc_am-materialscanspotlightecbuildinggreen2020.pdf.