WHITE PAPER

Integrating Embodied Carbon in Energy Planning

By Annie Kell and Chris Vaughan

Addressing the challenge of embodied carbon requires a multifaceted approach that combines planning, design and construction. By prioritizing sustainability from the outset, campus energy projects can make significant strides toward reducing their carbon footprint and contributing to global climate goals.

Embodied carbon, also known as embodied greenhouse gas (GHG) emissions, has become increasingly important as a new frontier for understanding the true scope of carbon generated by the built environment.

While operational carbon emissions are relatively straightforward to observe and quantify, they represent only a portion of the overall emissions from campus energy systems. Developing a robust approach for analyzing embodied carbon is essential for planning, designing and building future projects that truly minimize life cycle carbon emissions.

Importance of Embodied Carbon

When considering the carbon footprint of a building the focus is traditionally on operational carbon, which represents the greenhouse gases related to the energy used to operate a building. However, there is a significant carbon footprint associated with the physical building asset, known as embodied carbon. According to the Carbon Leadership Forum, "embodied carbon refers to the greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of building and infrastructure materials." The evaluation of embodied carbon is necessary to truly understand the full carbon impact of a building or a campus infrastructure system (Figure 1).

This holistic approach is important because the embodied carbon impact of infrastructure and building materials is a significant contributor to global carbon dioxide emissions, representing approximately 15% of global 2024 emissions according to research in Architecture 2030. Additionally, as energy sources are gradually decarbonized and the efficiency of building operations are improved, embodied carbon will represent an increasingly large percentage of total construction emissions. Architecture 2030's research also projects that embodied carbon will represent half of the total emissions associated with new construction from 2020 to 2050.

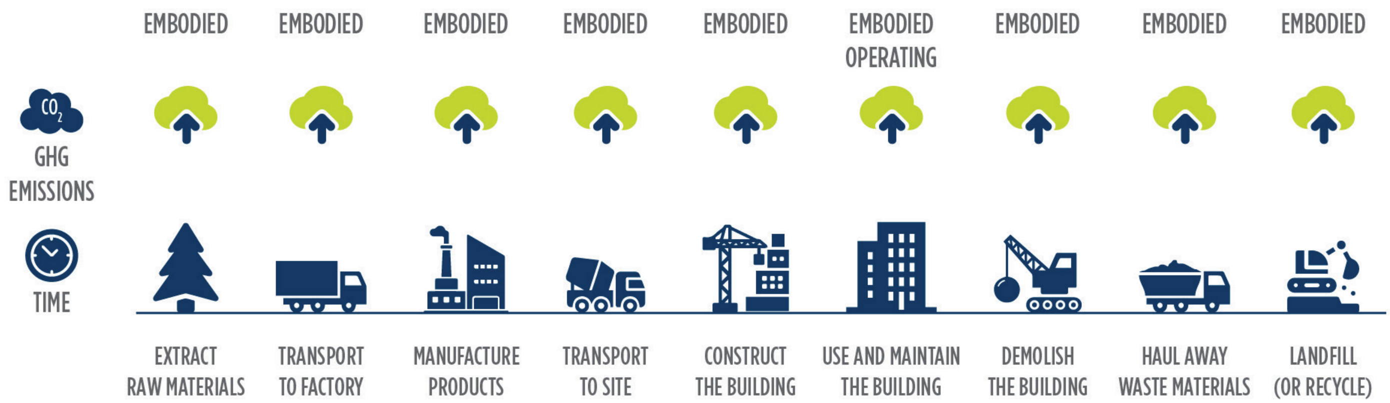

***Figure 1:** Embodied carbon is generated across all stages of a building's life cycle.*

Standard Tools for Assessing Embodied Carbon

An environmental product declaration (EPD) is a standardized document that summarizes the environmental impact of a product based on its life cycle analysis (LCA). An LCA evaluates six key environmental indicator categories:

1. Global warming potential (embodied carbon)
2. Depletion of the stratospheric ozone layer
3. Acidification of land and water sources
4. Eutrophication
5. Formation of tropospheric ozone
6. Depletion of nonrenewable energy resources

EPDs are intended to provide a transparent and credible method of comparing the impact of similar products. They can provide valuable data for generating practical embodied carbon projections for project design and construction.

A whole building life cycle assessment (WBLCA) is the standard approach for analyzing the embodied environmental impacts across a building's design, accounting for both quantities and types of material used to construct the building. The material quantities are used in conjunction with product-specific EPDs to determine the total impact of the proposed design. WBLCAs can also be leveraged to generate valuable insights on how alternative design choices will impact the total embodied carbon in the overall design.

Using Embodied Carbon Analysis for Campus Energy Projects

Due to the long-life cycle of many construction materials and systems employed in campus energy projects, embodied carbon analysis should be an important factor in shaping the decarbonization planning of future projects. While typical energy planning does not account for embodied carbon emissions, these emissions affect the environment just as much as operational carbon. In this context, deeper insights into embodied emissions can provide critical knowledge for further reducing the long-term environmental impact of campus energy projects.

The push for more manufacturers to generate EPDs, coupled with a growing multitude of tools and available data, has significantly improved the feasibility of evaluating a project's embodied carbon. Generating estimates at the early planning stages of a project is important for driving the greatest possible carbon reduction potential. According to Rocky Mountain Institute, 65%-85% of embodied carbon emissions result from the product phase, defined as the point of origin for product materials through the end of the manufacturing process. For this reason, efficient design and low-carbon material selection are important practices for reducing the overall embodied carbon of a project. Early analysis and integrative discussions between design disciplines and construction teams have proven successful in driving down the overall whole-life carbon of a project by balancing embodied carbon, operational carbon, budget, material availability and project schedule (Figure 2).

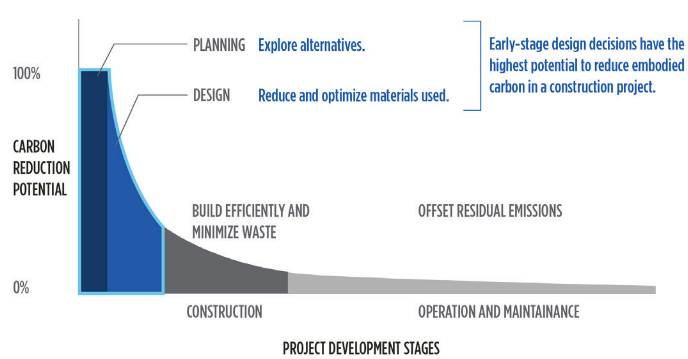

***Figure 2:** The graph shows the potential of reducing carbon emissions throughout a project's development stages.*

Component	Quantity	Carbon Factor	Safety Factor	Embodied Carbon ($MTCO_2e$)
Distribution	2,160 (tons)	4.13 $MTCO_2e$/Ton	10%	9,800
Plant Pipe	225 (tons)	4.13 $MTCO_2e$/Ton	15%	1,050
Pumps	1,500 (kW)	38 kg CO_2e/kW	0%	55
Chillers	3,750 (RT)	43 kg CO_2e/RT	25%	200
TES	250 (cu yd)	250 kg CO_2e/cu yd	15%	70
Additional Equipment and Electrical				200
Building and Misc.				180
Total				11,555

Figure 3: *Embodied carbon estimate for a campus conversion to hot water with heat pump chillers.*

Campus Energy Project Case Study

The following example walks through the analysis process for the embodied carbon impact of a campus-wide conversion from central steam to central hot water using heat pump chillers. The analysis is broken down into the various project components and compared, in summary, against the operational carbon savings. For this scenario, the embodied carbon projection encompasses manufacturing and transport to the site but does not account for construction activities or end-of-life carbon emissions.

The analysis begins with the distribution system, which will be responsible for transporting hot water across the entire campus and requires a large quantity of steel piping. Based on a projection that 2,160 tons of preinsulated steel will be required, carbon factors based on data sourced from industry-standard EPDs were applied to generate an aggregate estimate for embodied carbon for the distribution system. A safety factor of 10% helps account for uncertainty from EPD data and building distribution.

Distribution	2,160 (tons)	4.13 $MTCO_2e$/Ton	10%	9,800

The same logic allows for generating an embodied carbon estimate for the 225 tons of plant piping necessary for plant expansion to house heat pump chillers and hot water components. Here, a slightly larger safety factor of 15% helps account for valves, fittings and instrumentation required for the pipes.

Plant Pipe	225 (tons)	4.13 $MTCO_2e$/Ton	15%	1,050

An industry standard EPD also provided helpful data for a similar model of end suction centrifugal pumps to those used in the design. This EPD was scaled to the size of the project's required pump. In this case, close mechanical similarity allowed for a 0% safety factor.

Pumps	1,500 (kW)	38 kg CO_2e/kW	0%	55

EPDs were not available for the heat pump chillers used in this project design. To generate a workable estimate, a 25% safety factor was applied to the embodied carbon from the EPD for a standard centrifugal chiller from comparable manufacturers to account for a more complex industrial design and dual compressors.

Chillers	3,750 (RT)	43 kg CO_2e/RT	25%	200

A hot water Thermal Energy Storage (TES) tank would require 250 cubic yards of concrete, with a 15% safety factor added to account for tank internals, instrumentation and other associated complexities. Concrete EPDs are readily available online, and the industry also tracks average embodied carbon across several manufacturers.

TES	250 (cu yd)	250 kg CO_2e/cu yd	15%	70

After completing projections for the major embodied carbon factors outlined above, an additional 200 metric tons was added to account for additional equipment and systems required by the design, including electrical gear, heat exchangers, water treatment and various other components. This estimate is based on an assumption that the total steel and other materials in these additional components would be roughly comparable to those of the chillers.

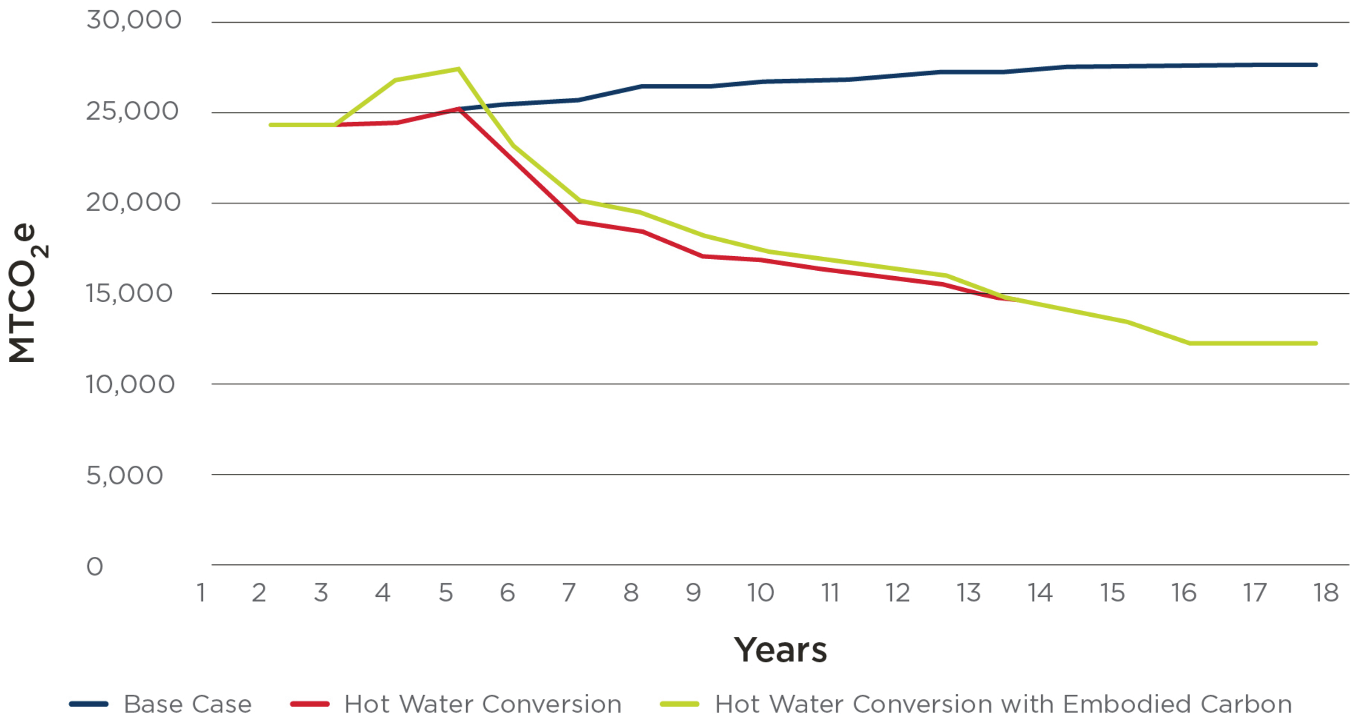

Figure 4: *Carbon emissions of the campus energy project over time.*

Finally, the building size and structural type give us a rough projection of 180 metric tons of carbon for the building's structure and enclosure. This projection aggregates to 11,555 metric tons of carbon that can reasonably be associated with the materials for this project. Note: This embodied carbon calculation did not account for construction activities, which can add an additional 6-10% of the total for the project.

Campus Energy Project: Comparison to Operational Carbon

For this project, operational carbon savings per year were projected at 9,100-14,000 MTCO2e versus a base case example that assumed the campus continues to utilize steam for heating. Because this project helps electrify the campus, the carbon savings range is based on variability in local grid emissions. When weighing the upfront "cost" of the embodied carbon of this project compared to the "savings" from the operational reduction, this project is projected to realize a carbon payoff in 10-15 months.

Figure 4 shows the anticipated carbon emissions per year from the base case project assuming the campus continues to use steam vs. the hot water project. An additional projection is also included for the hot water conversion demonstrating the impact of accounting for with and without embodied carbon.

How Embodied Carbon Will Shape Future Campus Energy Projects

As embodied carbon continues to become a more significant part of decarbonization planning, there are ample opportunities to help further develop the crucial knowledge base needed to perform these evaluations. Organizations can help drive the industry's more widespread adoption of embodied carbon analysis by contributing to datasets through EPD creation, TM65 analysis, participating in initiatives like MEP2040 and SE2050, and proactively supporting broader efforts to generate better data on the incredibly diverse array of systems and materials employed in campus energy projects.

Engaging with an embodied carbon consultant early in the project planning process can help maximize the impact of this analysis. Involving the construction team in these efforts can help extend this impact, as the team can help bring the actual design to life.

Evaluating the embodied carbon impact of possible alternative design choices, systems and materials early is recommended for incorporating these insights into decision-making processes and ultimately reducing the project's whole-life carbon emissions.

Helpful Standards and Resources for Embodied Carbon Analysis

Effectively an executive summary of LCAs, EPDs are verified by third parties. These documents make it dramatically easier to compare the impacts of alternative materials and ultimately inform decision-making to reduce embodied carbon emissions. EPDs may be available from vendors upon request and are publicly available from repositories including but not limited to:ma quaturi oribus enecatur?

- **The EPD Library, a project of the International EPD System**
- **The EPD Library of the North American EPD System**
- **Technical Memorandum 65 (TM65).** TM65 refers to guidance developed by the Chartered Institution of Building Services Engineers (CIBSE) on embodied carbon calculation methodology for building services This resource offers a standardized approach to assessing the embodied carbon of various components within building services, such as heating, ventilation and air conditioning systems, lighting, and controls. TM65 includes a detailed methodology for calculating embodied carbon, collecting data from suppliers and employing standardized conversion factors.
- **Structural Engineers 2050 Commitment Program (SE2050).** SE2050 is an initiative led by the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE) seeking to engage structural engineers in the challenge of achieving net zero embodied carbon in construction by the year 2050. Firms that commit to SE2050 must implement an embodied carbon action plan (ECAP) outlining specific strategies they will take to reduce embodied carbon. SE2050 offers a number of resources including data, EPDs and an embodied carbon estimation tool.
- **Mechanical, Electrical and Plumbing 2040 (MEP2040).** MEP 2040 is an initiative aimed at engaging the MEP engineering community in the global effort to achieve net zero operational and embodied carbon in building systems by the year 2040. It parallels SE2050 but focuses specifically on the MEP aspects of building design and construction.
- **Embodied Carbon in Construction Calculator (EC3).** The EC3 calculator is a free web-based tool developed by the Carbon Leadership Forum to promote more data-driven decisions for embodied carbon reduction.

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