You and Me, Carbon Free!

The objective of this challenge is to develop an innovative solution that will reduce carbon emissions from U.S. buildings (residential or commercial, new or existing). Problem statements can address embodied carbon emissions and/or operational carbon emissions. Innovative solutions should lead to significant reductions in carbon emissions and increased affordability for identified stakeholder groups to obtain new technologies.

Background

Buildings account for about 40% of energy-related carbon emissions worldwide.[1] **Carbon emissions** generally refer to carbon (primarily carbon dioxide, CO_2) that is released into the atmosphere—this contributes to greenhouse gases absorbing and emitting radiation, which warms the planet.[2] Energy-related carbon emissions come from a variety of sources, including the emissions related to energy consumption in buildings (both electricity and fossil fuels such as gas), known as **operational carbon emissions**. Emissions also come from material production and manufacturing, building construction and maintenance, and material end-of-life processing (e.g., separation, disposal, reuse, remanufacturing), known as **embodied carbon emissions**. Emissions from residential and commercial buildings in the United States match global trends, with annual operational carbon emissions totaling 29% of all U.S. emissions when the CO_2 emissions from the generation and distribution of electricity are included.[3]

The United States has committed to significantly reducing carbon emissions by 2030.[4] A unique characteristic of buildings—when compared to other carbon-emitting sectors such as transportation—is that buildings have a comparatively slower turnover rate. The average age of U.S. homes and commercial buildings is around 40 years old,[5] with projected life expectancies anywhere from 75 to 100 years or more.[6] Additionally, the U.S. population is projected to grow 20%–25% between now and 2060,[7] which will continue to increase demand for housing and commercial floor space. As with any multifaceted and complex problem, there are many opportunities for solutions addressing carbon reductions in our buildings—both operational and embodied.

The architectural and design community has been focused on employing strategies and processes to reduce **embodied carbon** for many years. Examples include design practices focused on renovation and reuse of existing buildings and materials, selecting building products that have minimal carbon emissions during production and manufacturing, and locally sourcing materials, when possible, to further minimize emissions related to transporting the materials for construction.[8]

The processes of building material production, building construction and demolition (C&D), and handling at the end of a material's first use present additional opportunities for embodied decarbonization. Generally, building materials follow a linear economy model, with large amounts of raw material, carbon, and energy inputs, and equally large amounts of waste and emissions as final outputs. In fact, 600 million tons of C&D materials were generated in the United States in 2018, which is twice the amount of municipal solid waste generated that year.[9] Demolition contributes 90% of total C&D debris generation.[10] Most materials have low recovery and reuse rates that offset the need for new material inputs for construction, demonstrating an opportunity for innovative material reuse. By adopting a more circular approach, known as a **circular economy**, carbon emissions and waste materials can be reduced. Circular approaches include designing out waste and pollution in extraction, processing, manufacturing, construction, and demolition processes, and keeping products and materials in use for as long as

possible.[10,11] Specifically for the building sector, circular approaches can include designing buildings for adaptability; optimizing design for reducing building material requirements; recovering, reusing, and recycling materials and systems; and industrializing construction and electrifying construction equipment.

In terms of **operational carbon,** opportunities for reduction include energy efficiency and electrification, as well as smart devices and equipment that enable connectivity between devices, buildings, and the electric grid to optimize energy consumption and minimize carbon emissions.[2] With more renewable sources of energy supporting the grid, electrification can help reduce operational carbon.

It is also important to consider how carbon emissions are **accounted** for throughout the lifetime of a building. Embodied carbon emissions are released during the construction, renovation, and demolition of a building, whereas operational carbon emissions are released continuously while a building is in operation. For example, 38% of total carbon emissions over the first 10 years for typical new construction built in 2020 will be the embodied carbon released due to construction—the remaining 62% are carbon emissions from operating the building.[12] However, when we compare typical new construction to high-performance construction, the story changes. Two-thirds of all carbon emissions over the first 10 years for a high-performance building will be the embodied carbon released due to construction.[13] The primary reason for this is the significant reduction in operational carbon emissions from energy efficiency measures taken as part of the high-performance design. However, there can be cases where the amount of carbon saved by a high-performance building would be less than the carbon emitted to create the building in the first place.[14] While life cycle analyses can be used to evaluate the carbon savings, solutions for both embodied and operational carbon are needed.

Additional research has studied the relationship between **carbon emissions and socioeconomic status.** Some data suggest that high socioeconomic status may disproportionately contribute to energy-driven carbon emissions related to consumption patterns. At the same time, substantial financial resources of high socioeconomic people can influence emissions, climate change policy, and mitigation efforts; however, these efforts may or may not be energy or carbon efficient.[13] Related research suggests that although high socioeconomic status may lead to higher consumption rates, these consumption patterns are often related to transport emissions, and lower socioeconomic status people are more likely to contribute to carbon emissions related to households.[15] Thus, careful consideration is needed to ensure the carbon reduction solutions meet the needs of—and are effective for—the stakeholder group.

The Challenge

This challenge asks student teams to develop an innovative solution that will reduce carbon emissions in buildings. Students can focus on any aspect related to carbon emissions, including but not limited to embodied carbon and/or operational carbon emissions. Teams should first develop a focused problem statement for a specific stakeholder group and then develop a technical solution or process.

Suggestions for student teams include (but are not limited to) the following:

- Create innovative design strategies and practices, such as:
    - Retrofitting building strategies that optimize reduction in carbon (operational carbon, embodied carbon, or both)
    - Building demolition practices that reduce waste and embodied carbon

    - Recovering, reusing, and remanufacturing practices for building materials that reduce waste and embodied carbon
    - Repurposing practices for existing commercial buildings for residential use
    - Industrializing on-site building construction processes
    - Site-planning that considers orientation of buildings and distribution of vegetation to improve operations and site material selection to reduce building maintenance.
- Present solutions with advanced controls that optimize building operation and minimize carbon emissions, such as:
    - Distributed energy resources and management systems and controls
    - Integrating connected lighting systems with plug load controls
    - Automated fault detection and diagnostics.

Student submissions should:

- Describe the scope and context of the chosen problem.
- Identify affected stakeholders, making sure to research stakeholder backgrounds and understand the stakeholders' needs, especially regarding the problem.
- Develop a technical solution to the chosen problem for the targeted stakeholder group. The solution may also include policy solutions, supply chain and manufacturing processes, economic solutions, or other aspects critical to identified stakeholder barriers, but a technical solution must be proposed.
- Discuss appropriate and expected impacts and benefits of the proposed solution. This should include expected carbon reduction analysis, a cost/benefit analysis, a market adoption analysis, and should also consider non-economic costs and benefits, such as occupant health, productivity, well-being, and others.
- Develop a plan that describes how the team envisions bringing its idea to scale in the market, including sales or distribution channels, outreach mechanisms, stakeholder engagement, and other relevant details.

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