Time Value of Carbon

When you save matters, what you build matters, what you *don't* build matters more.

By Larry Strain, FAIA

INTRODUCTION

Climate change is time critical. If we continue with business as usual, global temperatures are predicted to rise 2°C above preindustrial times by 2030; this temperature change is widely accepted by the world scientific community as the point at which climate change becomes irreversible and catastrophic, often referred to as the global tipping point. We are about half way there, the climate has warmed by about 1° C. In 2013, the International Panel on Climate Change (IPCC) ran a number of emissions scenarios and only one kept us below 2°C: That scenario had emissions peaking by 2020 and fossil fuels phased out by 2055. When we evaluate emission reduction strategies, there are two things to keep in mind: the *amount* of reduction, and *when* it happens. Because emissions are cumulative and because we have a limited amount of time to reduce them, carbon reductions now have more value than carbon reductions in the future. The next couple of decades are critical. This paper focuses on emissions from the built environment and strategies to reduce them, particularly on embodied rather than operating emissions.

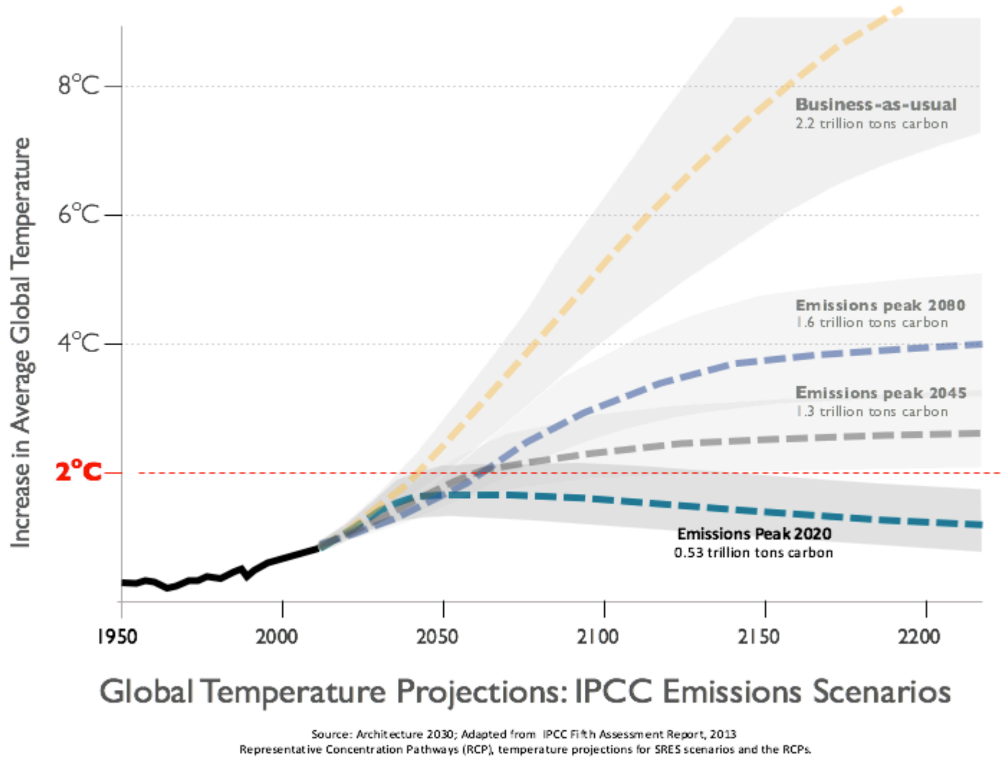


Figure 1. Emissions Scenarios

The following terms are used in this paper:

Carbon, Emissions and Greenhouse Gas emissions are used interchangeably and all refer to Green House Gas emissions (GHG) which are made up of Carbon Dioxide (CO_2) and other GHG's, all of which are expressed as Carbon Dioxide equivalents (CO_2e).

Embodied Carbon (eCO_2): GHG emissions from materials and construction.

Operating Carbon (oCO_2): GHG emissions from building operations — heating, cooling, lighting, plug loads.

BUILDING EMISSIONS

The built environment as an end user of fossil fuels is responsible for more emissions than any other sector. These emissions include emissions from building operations, (including electricity generation) and embodied emissions from materials and construction.

While constructing and operating buildings is responsible for almost half of U.S. GHG emissions, it also offers significant opportunities for reducing those emissions. The current gold standard for reducing emissions from buildings is to build new, net zero energy (NZE) buildings — very efficient, buildings powered by renewable energy sources, where the energy generated is equal to the energy needed to operate them. Because we build a lot of buildings, this is a critical piece of getting to a carbon neutral built environment. But there are two problems with relying on this strategy alone — building all of those new buildings will generate a lot of emissions and most building emissions come from less efficient existing buildings.

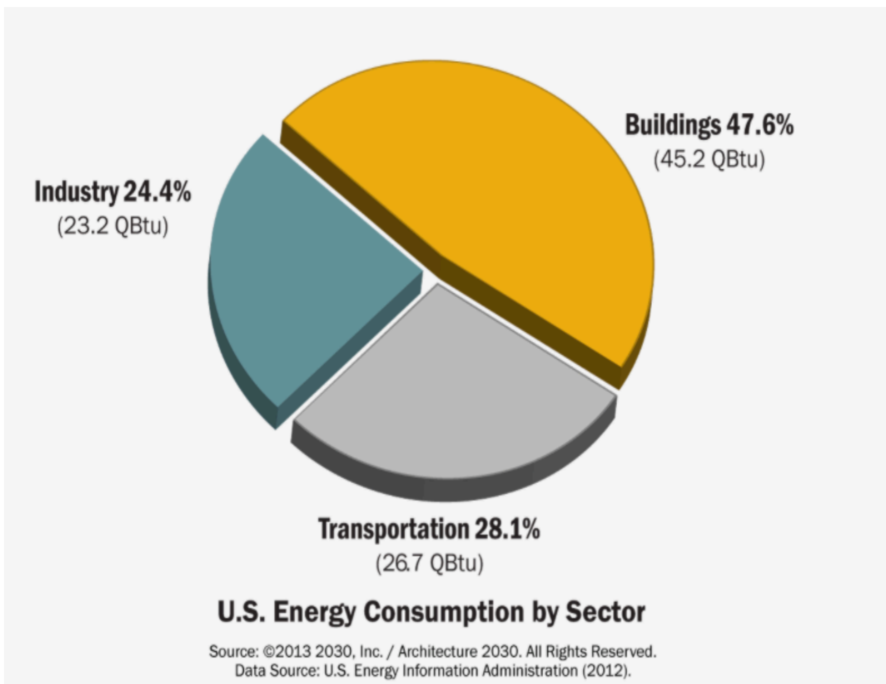


Figure 2. Consumption by End User Sector

Note: although energy use and GHG emissions are not the same, on a national scale, percentages for energy consumption and GHG emissions from buildings are roughly equivalent.

We need strategies that can produce large savings quickly, and because some reduction strategies result in an initial increase in carbon emissions from materials and construction — we need strategies that can produce *net reductions* within the next critical 10-30 years. Ultimately, we will need a built environment that is carbon neutral.

Ideally, all new buildings should be net zero energy (and emissions), but once buildings have eliminated operating emissions, two other sources of emissions become more important in the short term:

1. Embodied emissions from building materials, and construction processes.
2. Operating emissions from the existing buildings we already have.

NEW BUILDINGS: The importance of embodied carbon emissions (eCO_2)

When we started to really pay attention to energy efficiency after the first global energy crisis in the 1970s, we were focused on saving energy, not reducing GHG emissions, and embodied energy and their associated emissions were generally ignored. This was because over a building's lifespan, typically 75–100 years, embodied emissions only accounted for 10%-20% of a building's total emissions. But a couple of things have changed since then: GHG emissions have become more critical than energy; and as buildings have become more efficient and operating emissions have dropped, embodied emissions now make up a much larger percentage of total lifetime emissions. 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 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. If we succeed in making new buildings net zero energy (NZE), then the *only* emissions will be the embodied emissions. In the long run, it's still important that new buildings be NZE, but in the short term we need to focus on reducing embodied emissions.

This is not a simple thing to do. We know how to make NZE buildings, but it is much more difficult to reduce embodied emissions to zero. There are immediate steps we can take—reducing the quantity of the materials in our buildings and selecting materials with lower carbon footprints—but modern, industrial materials generate significant GHG emissions in their production. Ultimately the modern material economy will need to become a carbon neutral material economy.

THE SCALE OF THE PROBLEM

The U.S. is currently building about 6 billion sq. ft./year and demolishing about 1 billion sq. ft. — adding about 2% and replacing about 0.3% of our building stock. We build a lot more residential than commercial.

Residential: about 4.5 billion sf

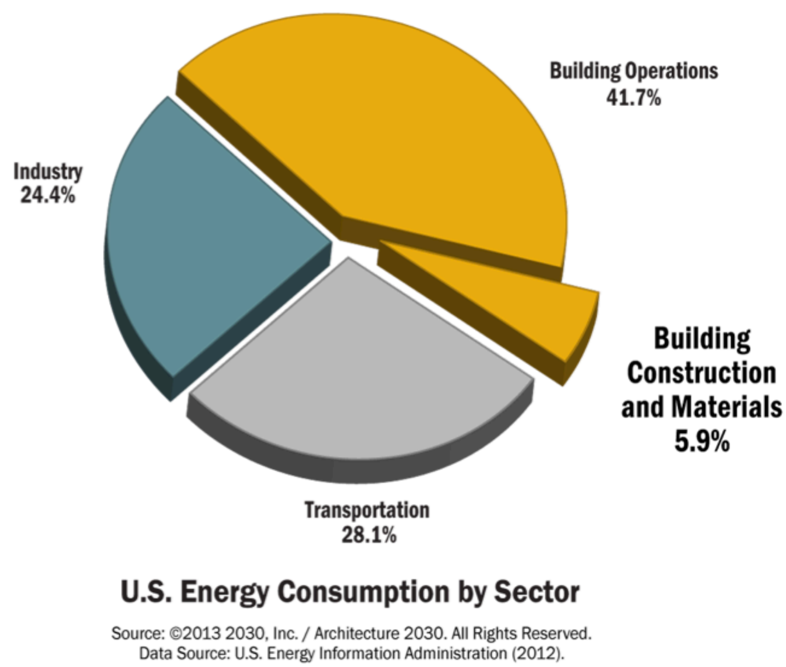
Commercial: about 1.5 billion sf

Energy Information Administration: averaged data from Residential Energy Consumption Survey (RECS) & Commercial Building Energy Consumption Survey (CBECS)

How much GHG emissions does this much construction release? There is currently no agency or organization that tracks embodied emissions nationally, but there are a couple of ways to estimate the embodied emissions from materials and construction.

The big picture, top down approach uses an Economic Input/Output Life Cycle Assessment (EIO LCA). EIO LCA's for construction assign emission factors per U.S. dollar of construction activity for different construction sectors of the economy—residential, commercial, manufacturing, and other categories of buildings. Carnegie Mellon has on-line EIO LCA models, that give emission factors for different sectors of the construction industry and McGraw Hill Construction/Dodge publishes annual construction data—square feet of construction and values of construction activity by building sector. Architecture 2030 puts annual U.S. eCO_2 emissions from materials and construction at 5.9% of total U.S. emissions (based on updated EIO LCA numbers from *Architecture and Energy,* Richard Stein).

Total U.S. emissions in 2013 were 6.3 billion **tons**.
5.9% of 6.3 billion = 370 million metric tons or about 700 kg /m^2



~ 370 million metric tons
700 kg/m^2 - (142lbs/sf^2)

Figure 3. Energy Use by End User Sector (Materials and Construction separated)
Note: although energy use and GHG emissions are not the same, on a national scale, percentages for energy consumption and GHG emissions are roughly equivalent.

The bottom up approach calculates environmental inputs and outputs (including GHG emissions) from all the materials and construction activities that go into making a building by conducting a whole building life cycle assessment (LCA). You would need do this for all the different building types and then multiply that by the total number of buildings we build each year. Whole building LCA's are becoming more common, but the number of buildings with whole building LCA's is still very small. Whole building LCA's use tools such as the *Athena Impact Estimator* that calculate environmental inputs and outputs from area take offs, or *Tally*—that gathers LCA data from Building Information Modeling (BIM), using Revit software.

The Carbon Leadership Forum (CLF) has taken the first step in collecting this data. They recently completed the *Embodied Carbon Benchmark Project*, gathering LCA data from over 1,000 building's, and used the results to establish initial eCO2 ranges for different types of buildings. The eCO_2 numbers from this study are lower than the numbers generated by EIO/LCA's: 100 – 400kg/m^2 (20–80lbs / $ft^{2)}$ for residential buildings and 290 - 500 kg/m^2 (60–100lbs / ft^2) for commercial buildings. This discrepancy may be explained by the fact that the whole building LCA's do not capture all the embodied emissions associated with constructing a building. Building systems and equipment, some of the transport emissions, site work and infrastructure, construction equipment, and some interior materials—are typically not accounted for in many LCA's. EIO/LCA's on the other hand are based on whole sectors of the economy and may capture emissions beyond the boundaries of the building.

For estimating annual embodied emissions at a national scale, EIO LCA's give a big picture overview of emissions by sector, but they don't tell us much about emissions associated with an individual building. For understanding emissions at the building level, whole building LCA's provide a wealth of detailed emissions data for different materials and building types. This is especially useful if we want to target reductions by material or building type. As whole building LCA's become more common, more of the data gaps will be filled in and the numbers will likely increase and get closer to the EIO/LCA numbers.

REDUCING EMBODIED CARBON

If we want to reduce embodied carbon it's useful to know where it is. The chart on the right shows a breakdown for embodied carbon for a typical office building in North America. As the chart shows, most of the carbon emissions from construction come from the materials we build with. Construction equipment, transporting workers and materials to the jobsite and site work also contribute emissions—for remote sites transport can be significant and for large sites, site work emissions can be a larger percentage—but typically the majority is from materials.

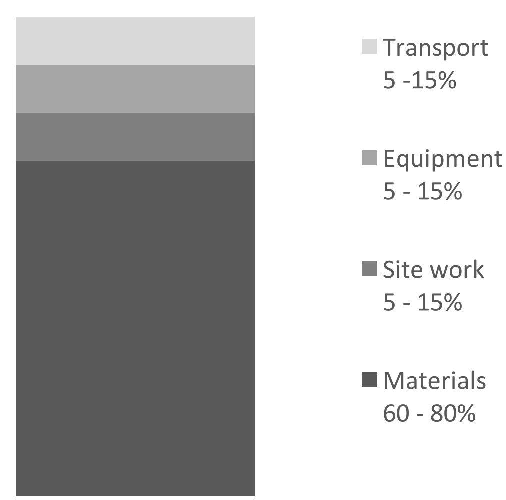


Figure 4. Where's the Carbon?
Source: Embodied Carbon Benchmark Project, and review of multiple embodied energy and carbon studies.

It's also useful to know the carbon footprint for different types of buildings and to understand how the materials and their carbon emissions are distributed (Figure 5). On a square foot basis, Larger heavier new buildings have a higher carbon footprint than smaller, lighter new buildings. Larger buildings weigh more per square foot because of what they are made of: beyond a certain size, buildings usually have steel or concrete structural systems, and steel and concrete have a larger carbon footprints than wood (although wood is now a viable alternative for large buildings). Small light buildings, at least in North America, have traditionally been framed in wood. It is worth noting that renovating even large, heavy buildings typically has a lower carbon footprint than building new small light buildings because you generally are not replacing the structural system which is where most of the embodied emissions are.

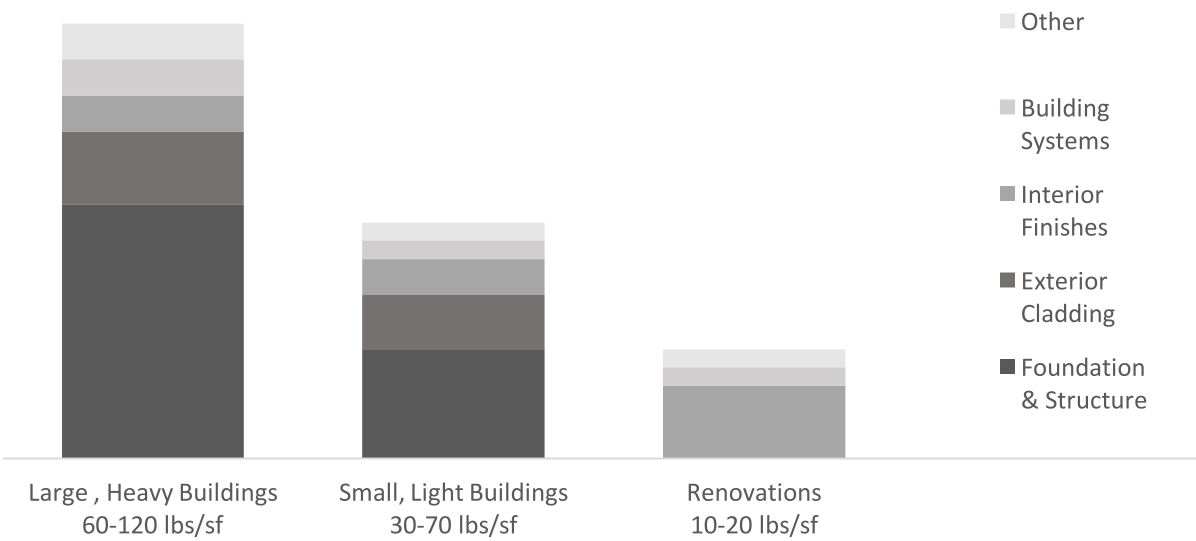


Figure 5. Carbon Emissions by Building Type and Building Element
Source: Embodied Carbon Benchmark Project, Carbon Leadership Forum, and review of multiple embodied energy and carbon studies.

REDUCING EMBODIED EMISSIONS: New Buildings
Reducing embodied emissions by 20-30%, is feasible right now using readily available materials and current technologies. Reducing material quantities, particularly high volume, heavy materials such as concrete and steel, and high emission materials such as metals and plastics, is particularly effective. Ways to achieve this include designing more efficient structural systems, minimizing waste, more efficient construction processes, and minimizing energy and emission intensive materials such as aluminum and glass curtain walls.

Using local, low embodied emission materials can reduce embodied carbon emissions even further. These materials are generally closer to their natural state—stone, clay, wood, straw—although when they aren't close to the building site, transportation emissions can be a significant impact, which can reduce the efficacy of using these materials.

There are also materials that sequester atmospheric carbon—plant based materials, including wood and agricultural bi-products, lock up GHG's that would otherwise be released when the material biodegrades or is burned, and there are emerging technologies for creating cementitious binders and aggregates from CO_2e captured from power plants, steel plants and other industrial smokestacks. Materials that sequester carbon theoretically can be used to create carbon neutral or even carbon negative buildings.

REDUCING EMBODIED EMISSIONS: Existing Buildings
But there is another way to reduce embodied emissions and that is to reuse existing buildings and materials rather than build new buildings. Building renovations generate significantly lower emissions than new construction, typically 50–75% less than new buildings generate.

Renovation projects have lower eCO_2 than new construction because they generally reuse the structure and building envelope, which account for the majority of the eCO_2 in a building. But even renovation projects generate embodied emissions, and we can reduce those if we pay attention. Renovation projects often remove and replace materials such as lay-in acoustic ceilings or worn out carpet. Instead of replacing them, we may be able to use the underlying structure as the new interior finish, reducing emissions, saving money, and transforming the space in the process. We can reuse the “waste” materials that are generated by renovation projects. New construction typically generates 3–5 lbs. of waste per square foot, but renovation projects can generate 20-30 times that much. When we reuse those “waste” materials instead of discarding them, we save carbon. We can use lower carbon materials to renovate building—insulating a metal warehouse with strawbales, using salvaged materials instead of new materials or even replacing synthetic carpet with natural fiber carpets.

We can also plan for future renovations, using building components that are easy to remove, clean, and refurbish. If people can change and renovate the buildings they already have more easily, they may be less likely to replace them.

REDUCING OPERATING EMISSIONS: Existing Buildings
Compared to building a new building renovating an existing building clearly saves embodied carbon emissions. But to get the most out of reusing existing buildings we also need to lower their operating emissions. Operating emissions from existing buildings are a much larger source of emissions than the embodied and operating emissions from new buildings and the reason is scale:

In the U.S., we are currently building about 6 billion square feet / year but we already occupy and operate about 310 billion sq. ft. Operating six billion square feet of new, efficient buildings generates about 40 million tons of GHG’s, less than 1% of total U.S. emissions. Building 6 billion square feet will generate about 350 million tons, just over 5% of our annual emissions, a significant number. But it doesn’t begin to compare with the 2.3 billion tons of operating emissions from our existing buildings—more than a third of U.S. annual emissions.

The majority of the buildings in use today will still be in use in 2030, so it is clear we need to reduce emissions from existing buildings.

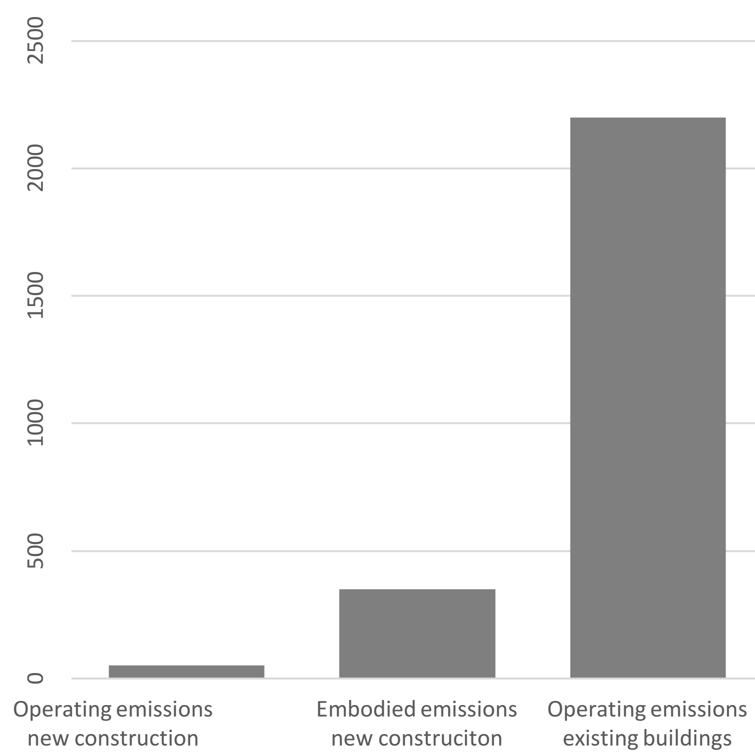


Figure 6. Annual Carbon Emissions
New Construction: 6 billion square feet
Existing Buildings: 310 billion square feet

REDUCING TOTAL EMISSIONS

Given the amount of embodied emissions from new construction and the amount of operating emissions from existing buildings, a combined strategy of reusing and upgrading existing buildings, building fewer new buildings and reducing embodied carbon emissions from construction is the most effective way to reduce emissions quickly. When the renovations include deep energy upgrades—even making existing buildings net zero energy and emissions, we address two sources of GHG missions at the same time—we reduce embodied emissions compared to new construction, and we reduce operating emissions from existing buildings by making them more efficient.

Reducing operating emissions is not technically difficult; we already know how to do it.

- Improve system efficiency - lighting, HVAC systems, equipment, controls, etc.
- Improve the building envelope – insulation, windows, shading, air sealing, daylighting
- Power them with renewable energy.

THE CASE FOR IMPROVING EXISTING BUILDINGS

We recently co-authored a study with the Integral Group of a two-story office building renovation and upgrade for DPR construction. This remodeled office building is currently generating more energy that it consumes, making a net positive building.
(http://www.ecobuildnetwork.org/projects/total-carbon-study)

The interior remodel upgraded equipment and lighting, added skylights and Photovoltaics (PVs), with only minimal upgrades to the envelope, (roof insulation). The remodel generated about 1/3 of the embodied emissions that building a new building would have, and because it is producing more power than it uses it is paying off that embodied carbon debt.

The building wasn't even a particularly ideal candidate for a net zero retrofit. It is partly shaded by taller buildings, and the single glazed aluminum storefront windows couldn't be replaced because they were historic. The most compelling part of this story is that even without ideal conditions, it still made sense to retrofit; the project came in on budget and on time.

The priorities for deep energy upgrades for existing buildings have changed over the last decade. In the past, you started by upgrading the building envelope—adding insulation and high performance windows, and maybe upgrading the lighting. With the use of blower-door tests and highly efficient and relatively inexpensive heat pump technology, air sealing and equipment upgrades are now also among the first upgrades we might undertake.

Efficiency strategies may vary depending on whether the building is residential or commercial. Commercial buildings generally have higher internal loads, which means that for commercial buildings, lighting and equipment upgrades may have a larger impact on reducing energy and emissions than envelope upgrades. Residential buildings tend to be dominated by external heating and cooling loads, and envelope upgrades may have a bigger impact, although appliances and equipment upgrades are also important.

Another thing that has changed is our understanding of the urgency of addressing climate change. As previously stated, we need to drastically reduce total carbon emissions—operating and embodied—over the next 10-30 years, and to do that we need to evaluate energy efficiency strategies based on the initial embodied carbon investment to achieve the strategy against the future operating savings generated from the efficiency upgrade. How much carbon did we spend to reduce operating emissions, and how long will it take the savings from increased efficiency and clean energy production to off-set that initial investment? When you do this analysis it may change your approach to efficiency upgrades. Blowing in insulation, re-commissioning or even replacing inefficient HVAC and lighting systems are likely to have a good return on carbon invested; re-skinning a building with a high-performance aluminum / glass curtain wall or wrapping the building in foam insulation may not be a good investment from a carbon standpoint. It may even make sense to add PVs before achieving that last few percent of efficiency. *The point is: we need carbon reduction strategies that have a positive payback within a 30-year time frame and ideally within 10 years.*

REUSE OPPORTUNITIES

Because reusing the foundation, structure and envelope saves a lot of embodied carbon compared to building new, some buildings are more important to reuse than others. Large, heavy commercial buildings offer a greater potential for reducing embodied emissions, because replacing this type of building will have a higher carbon footprint than replacing small residential structures. The good news is we have a lot of these buildings. There are almost 6 million commercial buildings in the U.S. and the majority are one- to three-story, flat-roofed buildings.

ENERGY EFFICIENCY OPPORTUNITIES

What are the best candidates for energy upgrades? We start with the buildings that use a lot of energy compared to similar buildings with similar uses. Poor performing buildings have a higher potential to save energy and reduce carbon emissions than more efficient buildings. These buildings usually have:

- Poor thermal envelopes, little or no insulation, single glazed windows, unshaded windows, leaky, drafty buildings.
- Old, inefficient HVAC and lighting systems and controls, and equipment and appliances.

NET ZERO OPPORTUNITIES[1]

Bringing existing buildings up to ASHRAE 90.1 2013— efficient but not necessarily to super-efficient —passive-house standards, would allow most of them to be converted to net zero energy. We have an abundance of one- to two-story strip malls, warehouses, schools and office buildings with large expanses of flat roofs, not to mention millions of single family homes. These are all prime candidates for efficiency and net zero upgrades.

The best candidates for zero net energy upgrades are:

- Buildings with unshaded flat roofs or south (in the northern hemisphere) and west facing sloped roofs.
- One- to three-story story buildings: 76% of commercial square footage and 96% of residential square footage are one- to three-stories.
- The majority of existing buildings in most climate zones—offices, retail, schools, warehouses, apartments and single family homes—could be converted to net zero energy.
- Buildings with adjacent unshaded land. Parking lots with PV canopies produce power and have the added benefit of shading the cars and pavement and reducing the heat island effect around the building.
- There are a number of building types and configurations that can’t be made NZE using only the roof and walls of the building—buildings over 4 stories, high energy use buildings such as restaurants, hospitals and data centers. These will require off site district or community based solutions.
- To also achieve net zero emissions, we also need to eliminate the use of on-site fossil fuel combustion and convert them to all electric.

ISSUES TO OVERCOME

- Identifying the best buildings to retrofit and upgrade to zero.
- There are limited incentives and regulations that require existing buildings be upgraded.
- It can be expensive to make an existing building more efficient and power it with renewable, clean energy.
- Addressing potential moisture and condensation issues when we upgrade existing buildings.
- All upgrades require an investment of eCO_2. We need simple ways to calculate the carbon invested and how long will it take the savings from increased efficiency to offset that investment.

FINAL THOUGHTS

- We still will need new buildings. Buildings wear out, priorities change, populations shift and grow, but we need to make reusing and upgrading existing building a much higher priority.
- Every building won't get to net zero, but we can make all existing building more efficient. We need to identify and target the best candidates and focus on them first, high energy use buildings and low-rise commercial and residential buildings. We could be retrofitting a lot more buildings to very low energy or ZNE.
- Reusing and upgrading existing buildings makes more sense in places that are mostly developed, such as the U.S. and the EU. For countries that are still building a lot of new buildings like China and India, the focus will need to be more on reducing the embodied carbon in new construction (as well as making them ZNE).
- Although this paper does not address transportation directly, locating buildings to minimize transportation impacts associated with building use is another a critical strategy for reducing emissions associated with buildings.

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