



White paper

The future is prefabricated

A Life Cycle Assessment (LCA) comparison of prefabricated modular and onsite-constructed concrete data centers.





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Executive summary

As digital infrastructure grows denser, operators face mounting pressure to deploy faster while cutting environmental impacts. Construction materials and methods drive a large share of a facility's carbon footprint through embodied carbon. Since these emissions are locked in from the start, operators evaluate lower-carbon design and construction options, such as prefabricated modular builds.

Prefabricated construction shifts the assembly to factories, reducing material use, waste, and logistics complexity. Modular designs with steel-framed shells lower carbon emissions through material efficiency and support higher IT load densities within a smaller footprint. To quantify the impact of this approach, a Life Cycle Assessment (LCA) compared the structural elements of a prefabricated steel-shell modular build to a traditional onsite concrete build.

The assessment found that concrete shell construction generated over twice the embodied carbon per square meter, while the prefabricated approach produced 3.5 times less carbon per megawatt (MW). These findings highlight the construction method as a major lever for reducing data center emissions on scale. As demand accelerates, how operators build will shape the industry's carbon trajectory for years.

Introduction

Constructing data center facilities, including structural shells, power delivery, cooling systems, and digital equipment, requires extensive material and energy inputs. From raw material extraction to manufacturing, transportation, and onsite assembly, every stage contributes to embodied carbon: emissions from the materials and methods collectively used to build the physical structure, built into the facility long before operations begin. These emissions are fixed at the outset and influenced directly by design and construction choices (see Figure 1).¹

Unlike energy-related emissions, embodied carbon

- Can't be reduced over time
- Can't be optimized later
- Remain part of the project's environmental footprint

Overview of greenhouse gas (GHG) protocol scopes and emissions across the value chain

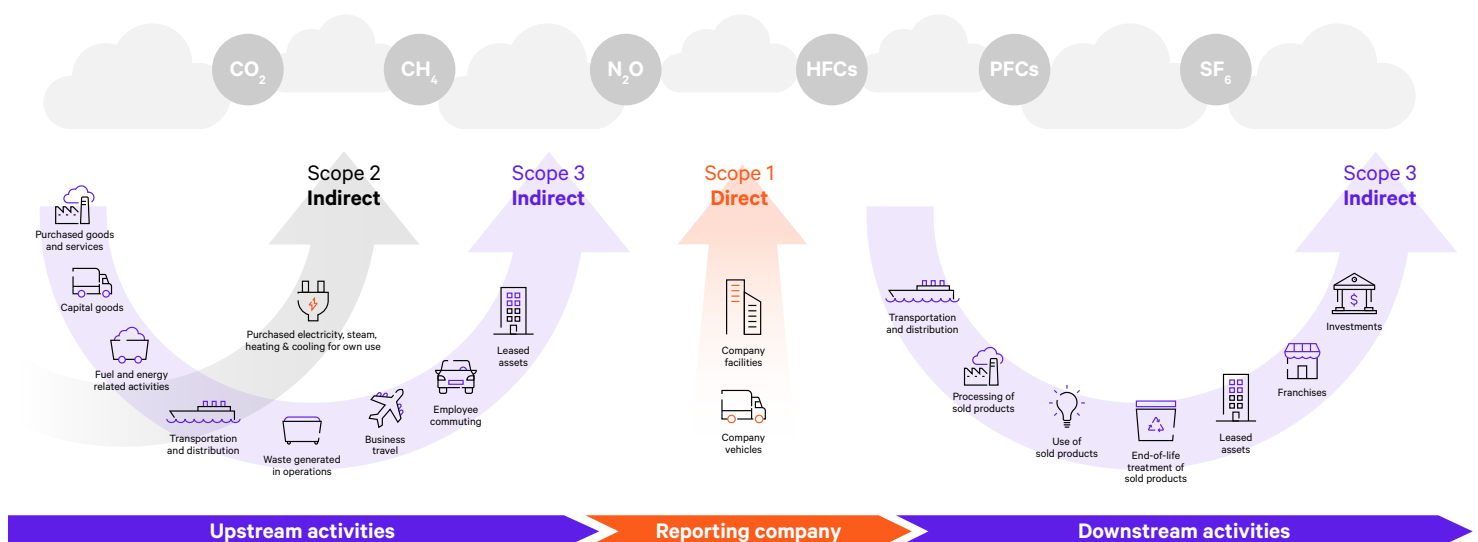


Figure 1. Overview of greenhouse gas (GHG) protocol scopes and emissions across the value chain. The United Nations Environment Programme (UNEP)'s 2024 Global Status Report shows that carbon dioxide (CO₂) emissions from the buildings and construction sector hit a record high of 9.8 gigatons in 2023.² Embodied carbon emissions were at 2.9 gigatons. While embodied carbon varies across building types, most is emitted early in the life cycle and can't be reduced later—especially in data centers. Image source: Environmental Protection Agency³

As demand for data center capacity grew, many operators looked closely at how construction methods influence total carbon performance.⁴ That shift reflected practical goals: aligning with emerging emissions reporting requirements,⁵ meeting customer expectations for lower-carbon infrastructure, and strengthening long-term efficiency at scale.⁶ For some, construction-stage decisions became a lever for improving resilience, deployment speed, and supply chain flexibility.⁷

Early solutions involving lower-carbon construction materials made important strides in improving the emissions profile.⁸ However, as data center demand accelerated, the industry needed approaches that could simultaneously deliver on three fronts: emissions reduction, rapid deployment, and hyperscale viability. Prefabricated construction methods, optimized material use, and streamlined logistics offer measurable ways to reduce a facility's embodied carbon without structural performance or scalability tradeoffs.

Prefabricated modular construction as an approach

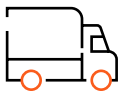
Prefabricated construction delivers data centers as factory-built, fully integrated building blocks. Each module includes structural framing, insulation, cable paths, containment zones, and cooling, power, and IT provisions. These modules are assembled and tested in controlled factory environments before being delivered to the site for final integration.

Prefabricated modular data center (also known in the industry as PMDC) construction offers clear advantages over traditional on-site builds. Parallel workstreams—simultaneous site

preparation and module fabrication—can reduce deployment time by up to 50%.⁹ Factory-controlled environments enhance quality, reduce rework, and enable efficient waste management, including material segregation and recycling. Modular approaches also maximize space utilization and simplify assembly, making them ideal for organizations prioritizing speed, reliability, and energy-efficient facilities.

Transforming infrastructure: Speed, space & savings

Market drivers



Accelerating deployment cycles

PMDC compared to onsite build

- Repeatable factory-integration to reduce deployment up to 50% and 50% less on-site work (including commissioning)
- Global supply-chain and service delivery footprint



Maximizing building blocks & space optimization

- Modular and hybrid solutions in multi-MW sizes
- Module design-practice saves up to 30% space

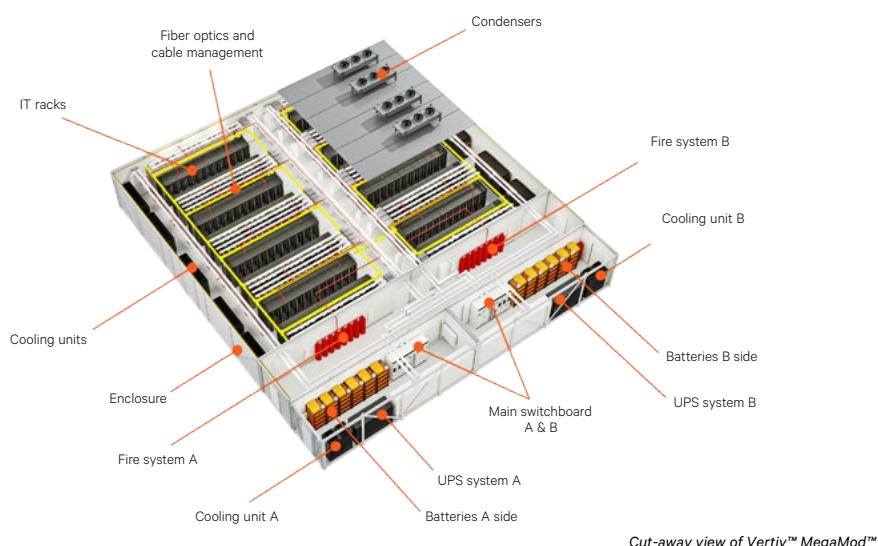


Reduce field work and improve build quality

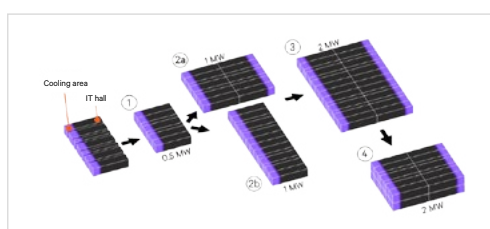
- Producing non-repeatable field work in the factory, improving build-quality and customer's total cost of ownership up to 25%

Recyclable steel framing structures form the core framework in many modular shells of innovative prefabricated modular (also known as PFM) data centers (see Figure 2). Steel offers high load-bearing capacity with lower material volume compared to concrete. This material supports repeatable assembly processes that improve consistency and standardization across deployments. When sourced from regional suppliers, structural steel enables shorter transport distances and better traceability of embodied carbon inputs.¹⁰

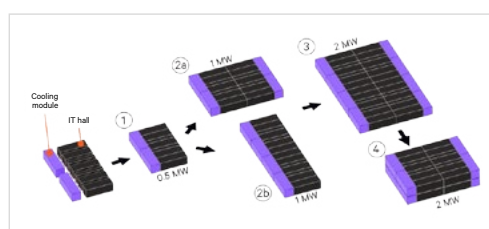
Component overview of Vertiv™ MegaMod™



Vertiv™ MegaMod™ options for expandability and stackability



Various building block layouts for Vertiv™ MegaMod™



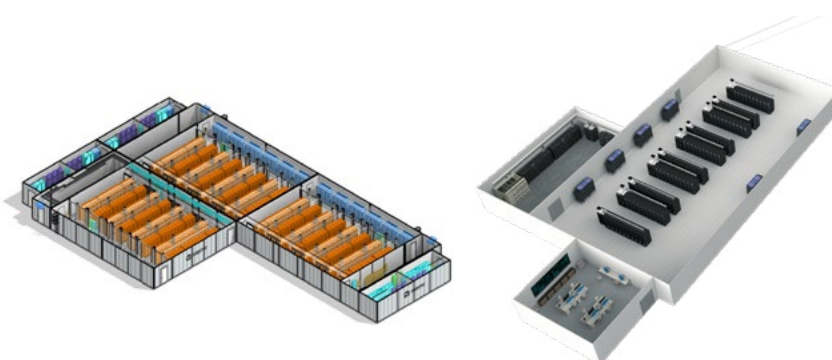
Various building block layouts for Vertiv™ MegaMod™ Plus

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Figure 2. Prefabricated modular (PFM) data center design combines scalable, rapid deployment with lower embodied carbon. Its steel-framed modules are assembled at regional facilities before site installation, supporting multiple infrastructure configurations in a compact footprint.¹¹ The system functions equally well as standalone data halls or expandable clusters for high-density workloads.

Factory-based workflows streamline construction by reducing onsite labor, material waste, and weather-related delays. Teams rely on grid electricity during module assembly, avoiding the higher carbon intensity associated with diesel-powered job sites.

To quantify these advantages, our researchers used the Life Cycle Assessment (LCA) to evaluate a 1.5-megawatt (MW) PMDC with steel-frame construction (see Figure 3) against a conventional concrete-shell facility with matching IT capacity and comparable physical footprint. This comparison incorporated actual material specifications, logistics networks, and assembly methodologies from established modular deployment platforms, providing measurable data on relative performance characteristics.



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Figure 3. A 1.5 MW Vertiv™ MegaMod™ prefabricated modular data center (PMDC) (left) and a representative onsite-built concrete data center model (right). The PMDC's recyclable steel design aims to lower embodied carbon and enhance material efficiency compared to the four-story concrete structure analyzed in the study.

Life Cycle Assessment (LCA)

An LCA measures the environmental impact of a building or product throughout its entire life cycle, including materials, construction, and disposal. Standardized with ISO 14040/44, LCA provides a holistic framework for comparing different construction approaches and supporting consistent, evidence-based decision-making in design and material selection.¹²

The LCA indicators, calculation rules, and system boundaries used in this study were based on the European Standard EN 15978:2011 (methodology “Sustainability of construction works—Assessment of environmental performance of buildings—Calculation method”)¹³ for evaluating the embodied carbon impact of prefabricated steel modules and conventional onsite concrete builds.

Scope, assumptions, and limits

The analysis used in this paper covers only embodied carbon (A1–A5, B5, C2–C4). The study excluded operational energy use, which is driven more by mechanical and electrical systems than structural material.

The researchers assumed a 50-year useful life for both prefabricated and traditional onsite builds.¹⁴ The model accounts for component replacements at intervals when their life spans fall short of this timeframe (see Figure 4), specifically:

- Product stage (A1–A3): Raw material extraction, manufacturing, and processing
- Transport to site (A4)
- Construction stage (A5)
- Refurbishment materials (B5), and
- End-of-life (C2–C4): Deconstruction, transport, and disposal

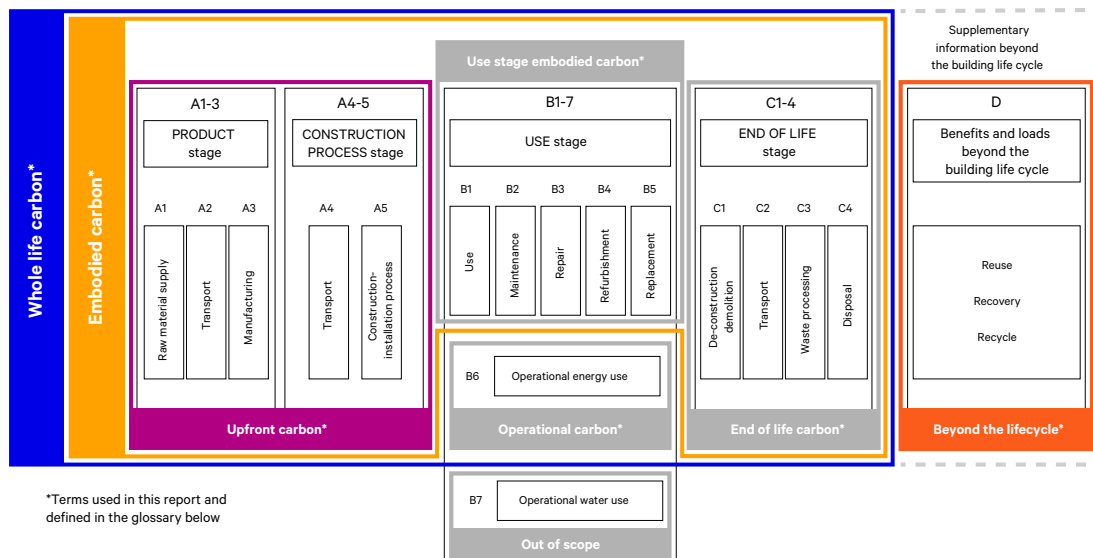


Figure 4. The life cycle parameters included in the analysis were based on EN 15978 under the factors contributing to embodied carbon and excluded operational energy and equipment.¹⁵

The study provides a high-level reference to guide data center deployment decisions. The data and methodology have not undergone third-party verification, so the study cannot be used for carbon emissions reporting. Accurate site analysis requires project-specific LCAs. Vertiv provides carbon emissions data for its prefabricated shells and other components to support these assessments.

Building scope boundaries

The assessment covered the data center's structural shell, including external and internal walls, roof, floor slab, partition walls, thermal insulation, and external doors. The scope focused on the white space where IT equipment operates and the electrical rooms that support critical loads. Material selections within these areas directly influence both structural performance and embodied carbon.

Building element group	Building element	Description
Piling and foundations (1.1)	1.1 Piling	Lowest floor frames
	1.1 Foundations (including pile caps)	Floor cross beams
	1.1 Lowest floor/slab	Earthing tape
Frame and roof frame (2.1, 2.3)	2.1 Frame	Floor frames
	2.3 Roof beams	Roof frames
		Roof beams
Upper floors/slabs inc roof (2.2, 2.3)	2.2 Upper floor/slabs	Columns and diagonals
	2.3 Roof	Roof panels, glues
		Roof sheeting, gutters, enclosure, blinds
Structural walls and stairs (2.4, 2.5)	2.4 Stairs and ramps	Waterproof membranes
	2.5 Structural external walls	External wall panels
		Thermal insulation
External doors and windows (2.6)	2.6 External doors	External fireproof doors
		Canopy
Internal walls and partitions (2.7)	2.7 Structural internal walls	Fireproof wall boards
Internal doors (2.8)	2.8 Internal doors	Door columns and door leaves
Other	3.1 Internal finishes	Vinyl flooring
		Floorboards
		Plywood boards
		Fire-rated sealant

Table 1. Elements of the structural carbon tool used to perform the LCA, categorized according to EN 15978 guidelines.¹⁶

The analysis excluded three elements for specific reasons:

- **Mechanical and electrical systems and IT equipment:** The embodied carbon remains consistent whether housed in steel or concrete shells.
- **Operational energy use (Stage B6):** Energy consumption depends primarily on equipment efficiency and workload, not shell materials.
- **Office and administrative spaces:** These areas don't contribute to core data center operations.

Data sources

The LCA relied on data gathered from as-built documentation, bills of material (BOMs) for prefabricated modules, and construction logs from traditional concrete builds. They quantified environmental impact using Environmental Product Declarations (EPDs)¹⁷ for all major materials. When product-specific EPDs were unavailable, functionally equivalent declarations were used based on material composition and performance characteristics.

High-quality input data is critical to producing reliable LCA. Complete and traceable material data allows infrastructure teams to make more informed carbon-related decisions across construction options. Factory-controlled production environments offer greater measurement precision and consistency. In contrast, traditional builds introduce more variability due to inconsistent site conditions, waste handling, and local sourcing practices.

Data quality	Onsite-built concrete structures	Prefabricated modules
Consistency	LCA data can vary significantly due to site-specific conditions, such as material sourcing, transportation, and construction methods.	Factory-controlled conditions standardize inputs.
Accuracy	Variability in labor efficiency and waste generation affects the accuracy of environmental impact assessments.	Standardized material inputs and manufacturing processes improve data accuracy.
Completeness	LCA data often lacks completeness in tracking material waste, transportation emissions, and energy use.	LCA data for the entire modular building is collected at the factory level.
Traceability	Supplier and subcontractor variabilities lead to gaps in traceability.	Prefabrication often relies on consistent suppliers, improving traceability across the entire life cycle.

Table 2. Summary comparing LCA data quality of a traditional data center and prefabricated modules. Comparison of material data quality across key categories, highlighting improved consistency and traceability in prefabricated systems.¹⁸

Life cycle stage analysis

A1–A3: Material production

The onsite-built concrete structure model generated approximately 97% more greenhouse gas (GHG) emissions per square meter than the prefabricated steel shell (Figure 5). This difference reflects variations in the quantity of material used and the carbon intensity of each material.

Concrete-based structures require more mass to meet load-bearing demands, especially in walls and floor slabs. Most of their embodied carbon comes from cement production, where limestone calcination and kiln operations emit large amounts of CO₂.¹⁹ Conventional casting methods add further impact through formwork, curing, and material waste. In contrast, the prefabricated shell used structural steel, which has a higher carbon intensity per kilogram but requires far less material to meet the same structural performance.²⁰

While supplementary cementitious materials can reduce concrete's carbon footprint, prefabricated steel systems can deliver better carbon performance through:

- Optimized material efficiency through factory-controlled fabrication.
- Near-zero jobsite waste (compared to concrete's typical 5-10% overage)
- End-of-life recyclability exceeding 90% recovery rates.

Steel can also incorporate higher levels of recycled content during production. Combined, these factors helped reduce upstream emissions in the production stage. Precise material engineering in the prefabricated design minimizes excess usage, contributing further to lower emissions. Prefabricated data centers using steel made with hydrogen and alternative energy, rather than fossil fuels, can achieve significantly lower embodied carbon.

Structural material selection

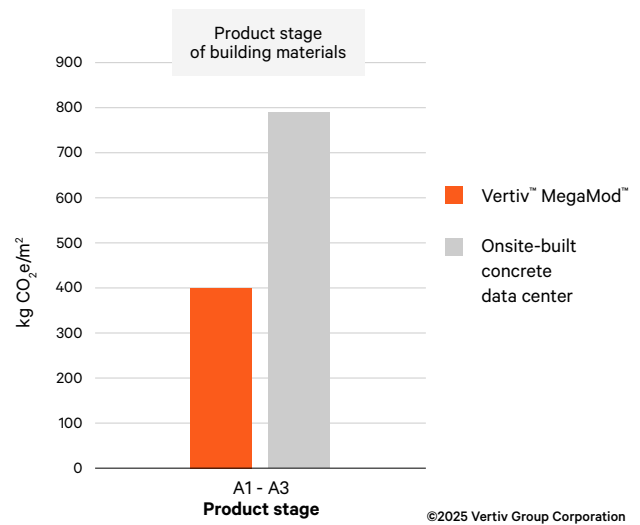


Figure 5. Greenhouse gas emissions per square meter compare the carbon impacts of materials used in prefabricated steel shells and onsite-built concrete structures.

A4: Transport to site

In the transport stage, the LCA showed that the PMDC model generated about 25% more emissions than onsite construction in the scenario studied (see Figure 6). The assumed 1,000-kilometer distance between the factory and installation site caused this difference. The model includes emissions from delivering raw materials to the factory and from transporting assembled modules to the site. Traditional builds in the model sourced materials locally and traveled shorter distances. In practice, PMDC transport emissions vary based on the distance to manufacturing facilities. These emissions could decrease as factory networks expand.

Transport emissions for prefabricated steel and onsite methods

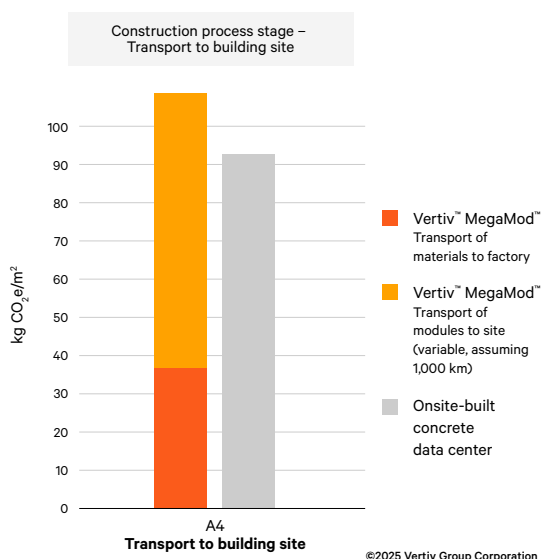


Figure 6. Estimated transport emissions between prefabricated module delivery and onsite construction.

Prefabricated modules (PFMs) are built off-site and delivered as complete units, which cuts down on vehicle trips and fuel use. Delivering fully assembled sections in bulk, instead of making frequent raw material deliveries, lowers transportation-related emissions.²¹

In contrast, traditional concrete construction involves multiple trips to transport cement, sand, aggregate, and steel reinforcement bars, along with formwork and onsite mixing equipment. This fragmented approach increases fuel consumption and transport-related emissions.

A5: Construction process

The LCA showed that construction waste emissions for the steel-shelled prefabricated modular data center (PMDC) model were about 4% lower than those for the onsite construction approach in the scenario studied (see Figure 7). In the PMDC model, this total came from two stages: factory production and onsite assembly.

Construction waste emissions from steel modular and concrete builds

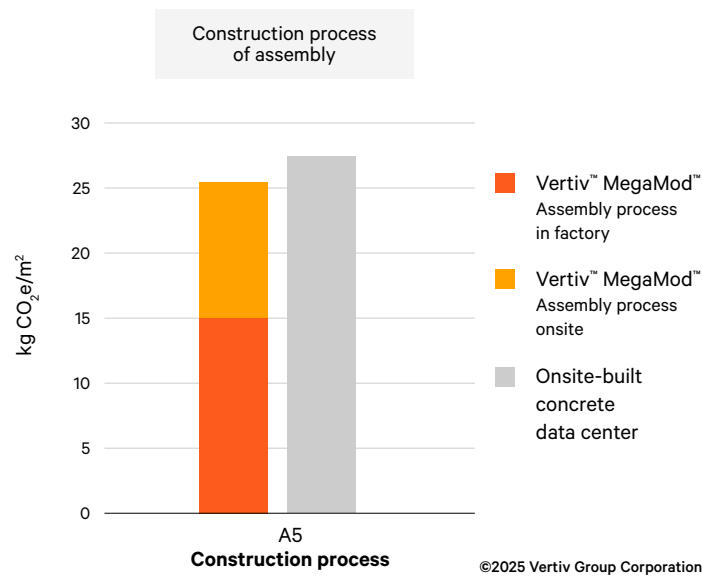


Figure 7. Construction waste emissions from the prefabricated modular data center (PMDC) with steel-shelled build and onsite construction with concrete build.

Onsite assembly of prefabricated modules produces less construction waste and uses less energy than traditional concrete builds. Factory-made components are pre-cut and tailored to specifications, which prevents overordering and minimizes excess scrap. Site assembly involves fewer wet processes, shortening construction timelines and reducing the need for temporary infrastructure like diesel-powered curing equipment and site lighting. Research shows that off-site construction can lower waste to 1.8%, compared to the 30% waste generated by conventional methods.²²

In contrast, traditional construction methods result in significantly higher material waste, inconsistent labor productivity, and greater equipment energy use. Weather-related delays and material degradation further hinder overall efficiency.

B5: Use phase and adaptability

The analysis of material-related emissions for upgrades and refurbishment highlights the prefabricated system's flexibility for IT refresh cycles, layout reconfigurations, and cooling retrofits. Steel modules allow selective replacement or expansion with minimal structural demolition.

In contrast, concrete shell data centers face inherent adaptability challenges. The fixed layouts and rigid structures complicate modifications for new cooling solutions or evolving IT infrastructure, often requiring costly demolition and reconstruction. While durable, concrete facilities demand extensive retrofitting to support technologies like liquid cooling or high-density racks—a process that typically causes operational disruption and extended downtime. These constraints stem from concrete's static nature, which limits airflow adjustments and infrastructure updates compared to more flexible alternatives.

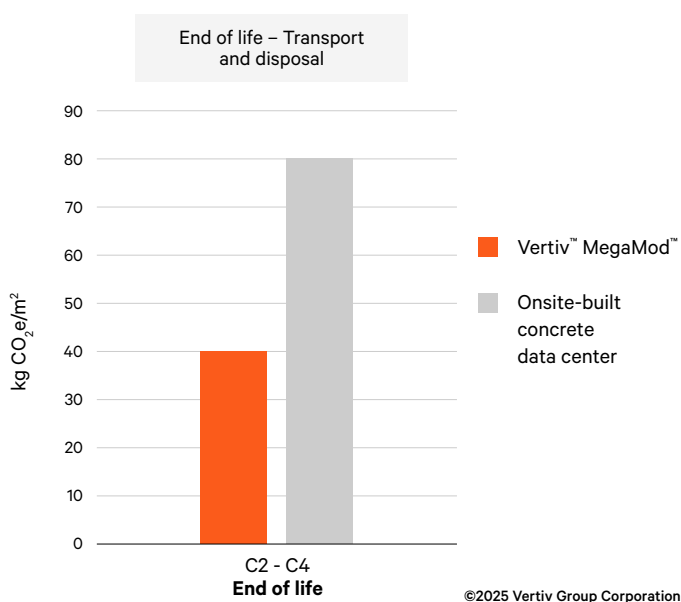


C: End of life stage

In the LCA, the steel-shelled PMDC model emitted about 49% less at end-of-life than the onsite concrete construction. The difference comes from how each structure is decommissioned.

Prefabricated steel shells enable straightforward disassembly. Components can be deconstructed using light machinery and separated for recycling or reuse. Modular framing systems support circular material flows, minimizing landfill volume. A bolted frame design is also an option, offering improved assembly efficiency and flexibility. Factory evaluations and supplier testing have confirmed that most cladding elements can be dismantled and reassembled multiple times.²³

End-of-life waste from steel and concrete materials



In comparison, demolishing a concrete structure requires heavier equipment. The process demands more labor and generates more mixed construction debris. Most of this debris can only be downcycled into low-grade aggregates. This leads to higher carbon emissions and increased waste disposal costs.²⁴

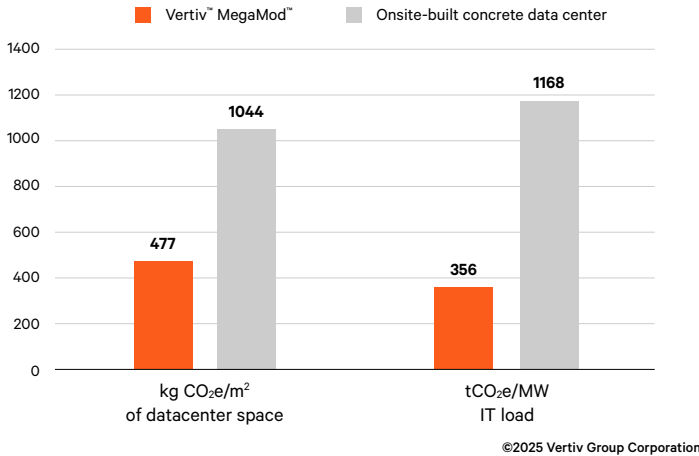
Figure 8. End-of-life waste outcomes for steel and concrete construction materials.

D: Benefits beyond the life cycle

Steel's high recyclability provides material value even beyond decommissioning. Unlike concrete, steel maintains its structural integrity through repeated recycling cycles.²⁵ Many steel suppliers now offer materials with over 90% recycled content. The future use of "green steel" (steel produced with hydrogen or alternative electricity) could further reduce upstream emissions. Modular construction also opens the door for future reuse. If a facility is relocated, upgraded, or replaced, intact steel modules can be removed and redeployed rather than discarded.

Life Cycle Assessment (LCA) results

Total embodied carbon by construction type



Overall, the LCA shows that the steel-shelled PMDC model generates lower embodied carbon than onsite-built concrete shells when normalized by both area and functional capacity. The prefabricated steel data center shell model emitted about 57% less greenhouse gas than a comparable concrete build (see Figure 8).

Figure 9. Total embodied carbon by construction type. This compares the embodied carbon emissions per square meter of the structural shell between prefabricated steel modules and traditional concrete construction.

When measured by IT load or kilograms of carbon dioxide equivalent per megawatt (kgCO₂e/MW), the difference widens due to better space utilization and design integration in the prefabricated construction model. This results in a carbon footprint roughly three and a half times lower than the traditional infrastructure. The benefits are visible across the life cycle as summarized in Figure 10, with material and product selection (A1-A3) being the most significant contributors to the carbon footprint.

Overall life cycle assessment comparison

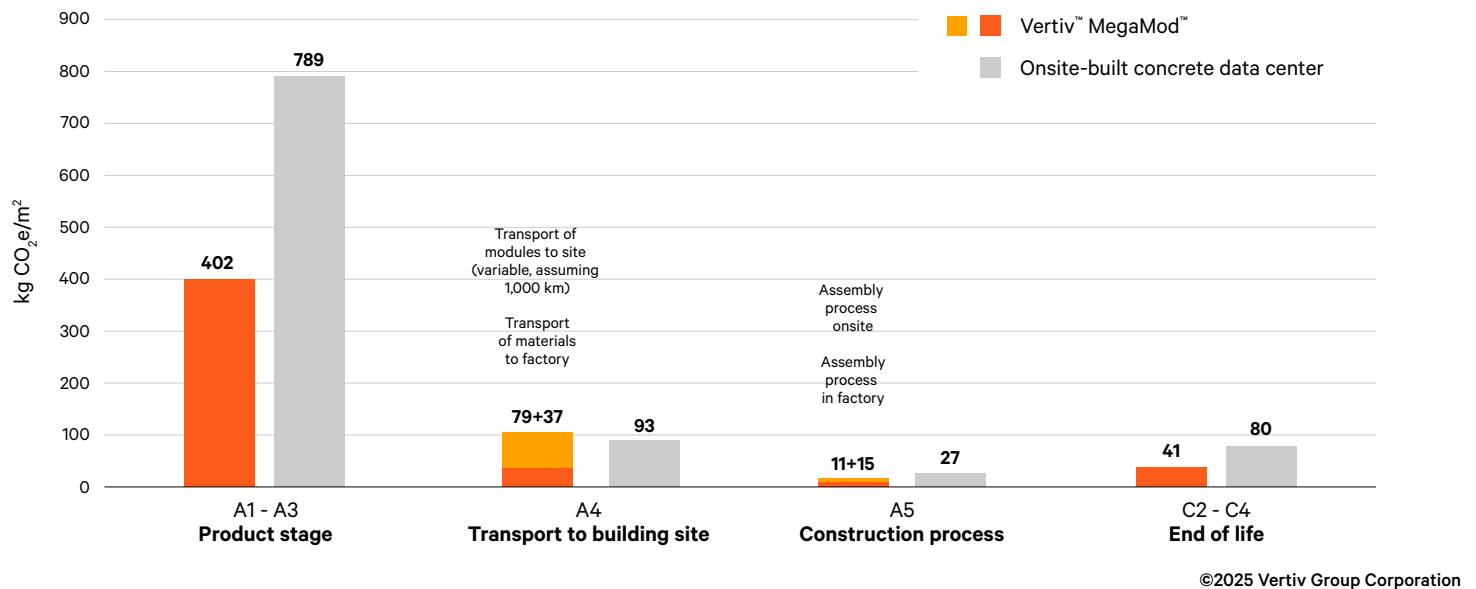


Figure 10. Overall LCA results comparison

The largest contributor to this difference was material efficiency. Steel has a higher carbon intensity per kilogram than concrete, but the prefabricated system uses less total material to meet the same load-bearing requirements. Other contributing factors include factory-controlled waste management, simplified logistics, and lower emissions during assembly.



Analysis and recommendations

New and increasingly complex problems require new approaches and the exploration of available and future technologies to address evolving challenges. Compared to traditional practices, design, manufacturing, and construction and assembly teams work closely together in prefabricated modular construction to meet operators' design, business, operational, legal, and forward-looking requirements. This allows operators, manufacturers, and assembly teams to see the unique perspectives, concerns, and plans for the business's needs ahead, consider life cycles from design to end-of-life, and continue collaborating even after the data center has been delivered and is operational.

Footprint efficiency

Prefabricated modular (PFM) designs create stronger links between design and construction, enabling teams to shrink the overall building footprint without limiting IT capacity. A smaller footprint for the same IT load also reduces the required structural material, which can cut embodied carbon.

Higher load density also minimizes supporting infrastructure per megawatt, fewer walls, less roofing, and smaller floor slabs, all of which compound to reduce total material mass and carbon emissions. This impact becomes more pronounced at scale, where small efficiency gains per module multiply across large deployments.

Beyond steel: Prefabricating with timber

Steel works well for modular data center construction, but other structural materials can offer additional carbon reduction potential. One example is cross-laminated timber (CLT), a carbon-storing material increasingly used in modular building applications. Unlike steel, which emits carbon during production, CLT locks in carbon absorbed during tree growth. When sourced from responsibly managed forests, it can significantly lower embodied carbon, particularly in low- to mid-rise data center shells where structural loads remain within timber's performance range.

Timber is also lighter than concrete and steel, reducing transportation emissions. Like steel modules, prefabricated timber systems are built in factory environments, assembled rapidly onsite, and follow the same principles of standardization, precision, and controlled material use.²⁶

Future trends

Vertiv™ prefabricated modular (PFM) systems are evolving to support energy-intensive workloads while helping reduce resource use across the life cycle. Vertiv™ MegaMod™ CoolChip integrates liquid cooling and factory assembly to handle high-density IT loads and reduce deployment time by up to 50%. Vertiv™ TimberMod™, built with engineered wood, is a lower-impact alternative to steel or concrete shells.

Power modules are also shifting toward site-level flexibility. Vertiv designs support microgrid compatibility and integrated controls. Vertiv is exploring hydrogen fuel cells for data center power systems to help sites reduce onsite emissions and manage utility constraints.

Building on Vertiv MegaMod, which supports up to 10 kilowatts (kW) per rack, Vertiv™ OneCore advances modular data center design, purpose-built for high-density AI workloads. Like Vertiv MegaMod, Vertiv™ OneCore involves onsite assembly of steel modules, instead of in-situ poured concrete. Controlled factory-based manufacturing can minimize waste and support resource efficiency.

Looking ahead, PFMs will support faster, repeatable infrastructure builds with reduced onsite labor and emissions. Engineers planning future capacity should focus on modular systems designed for energy, water, and material efficiency. Features like integrated cooling, serviceable components, and lower-carbon materials will be central to meeting operational targets—especially as AI-related power and cooling demands scale rapidly.



Reducing carbon starts at the shell

Prefabricated construction offers clear embodied carbon advantages over traditional concrete builds for data center shells. By using less material to achieve equivalent structural performance, the prefabricated steel approach reduced total embodied carbon by more than 50% per square meter and even more when normalized per megawatt of IT load.

Factory-controlled processes allow tighter quality control, lower waste generation, and more efficient transport logistics. Modular construction improved upgrade flexibility and end-of-life material recovery, supporting long-term responsible business goals without compromising performance or scalability.

As data center developers face growing pressure to deliver capacity fast and responsibly, prefabricated construction methods offer a practical way to reduce construction-related emissions and improve deployment efficiency.



Glossary

Bills of material (BOMs): A detailed list of raw materials, components, and assemblies required to construct a product or building. BOMs are critical for tracking material use and environmental impact in life cycle assessments.

Cross-laminated timber (CLT): A building material made from layers of wood glued together, known for its strength and ability to store carbon.

Circular material flows: A system where materials are reused, recycled, or repurposed at the end of their life cycle to minimize waste.

Embodied carbon: The total greenhouse gas emissions generated during the production, transportation, and construction of building materials, as well as their end-of-life disposal.

End-of-life (EOL) stage: The final phase of a product or building's life cycle, involving deconstruction, recycling, or disposal.

Environmental Product Declaration (EPD): A standardized document that provides data on the environmental impact of a product, including its carbon footprint.

Green steel: Steel produced using hydrogen or alternative energy sources instead of fossil fuels, reducing its carbon footprint.

Hydrogen steel: Steel produced using hydrogen as a reducing agent instead of carbon, significantly lowering emissions during production.

Kilograms of carbon dioxide equivalent per megawatt (kgCO₂e/MW): A unit of measurement used to quantify greenhouse gas emissions relative to the energy capacity (in megawatts) of a system or facility.

Kilograms of carbon dioxide equivalent per square meter (kgCO₂e/m²): A unit of measurement used to quantify the greenhouse gas emissions associated with a building or material, normalized by its area. It allows for direct comparisons of embodied carbon across different construction methods or materials.

Life Cycle Assessment (LCA): A methodology for evaluating the environmental impact of a product or building throughout its entire life cycle, from raw material extraction to disposal.

Load-bearing capacity: The ability of a structural element to support weight or pressure without failing.

Prefabricated construction: A construction method where building components are manufactured off-site in a controlled factory environment and then transported to the site for assembly, reducing waste, material use, and construction time.

Prefabricated modular data centers (PMDCs): Factory-built, fully integrated data center modules that include structural framing, insulation, cable paths, cooling, power, and IT provisions. These modules are assembled off-site and delivered for rapid onsite integration.

Scope 3 emissions: Indirect greenhouse gas emissions that occur in a company's value chain, such as those from material production and transportation.

Structural steel: A high-strength, recyclable material used in construction for its load-bearing capacity and durability.

Supplementary cementitious materials (SCMs): Materials like fly ash or slag that are used to partially replace cement in concrete, reducing its carbon footprint.

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