Why Embodied Carbon Matters, and What You Should Do About It

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REBUILD 2021

October 7, 2021

BALL STATE UNIVERSITY

browning day

Meet Your Speaker

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browning day

Learning Objectives: 1.0 AIA CE Hour

Learning Objective 1: Participants will be able to define embodied carbon and its basic metrics.

Learning Objective 2: Participants will be able to explain the different stages of lifecycle assessment (LCA) and why they matter to embodied carbon data.

Learning Objective 3: Participants will be able to describe ways of gauging and optimizing projects for lower embodied carbon as part of a building design workflow.

Learning Objective 4: Participants will be able to identify ways in which embodied carbon metrics are becoming integral to green building rating systems.

AIA Continuing Education

Learning Objectives: 1.0 GBCI LU (BD+C Specific)

Learning Objective 1: Define embodied carbon and understand its basic characteristics and metrics.

Learning Objective 2: Explain a workflow to optimize a project for minimal embodied carbon in accordance with the LEED v4 BD+C Building Life-Cycle Impact Reduction credit.

Learning Objective 3: Describe how LEED v4 BD+C can assist in gauging and optimizing building products and materials through disclosure documents such as environmental product declarations (EPDs).

Learning Objective 4: Identify ways in which embodied carbon metrics are becoming integral to LEED v4 BD+C as part an Integrative Process.

GBCI GREEN BUSINESS CERTIFICATION INC.™

LEED AP BD+C™

Part 1: Global context on carbon emissions

Part 2: Defining embodied carbon for buildings

Part 3: Modeling and measuring embodied carbon

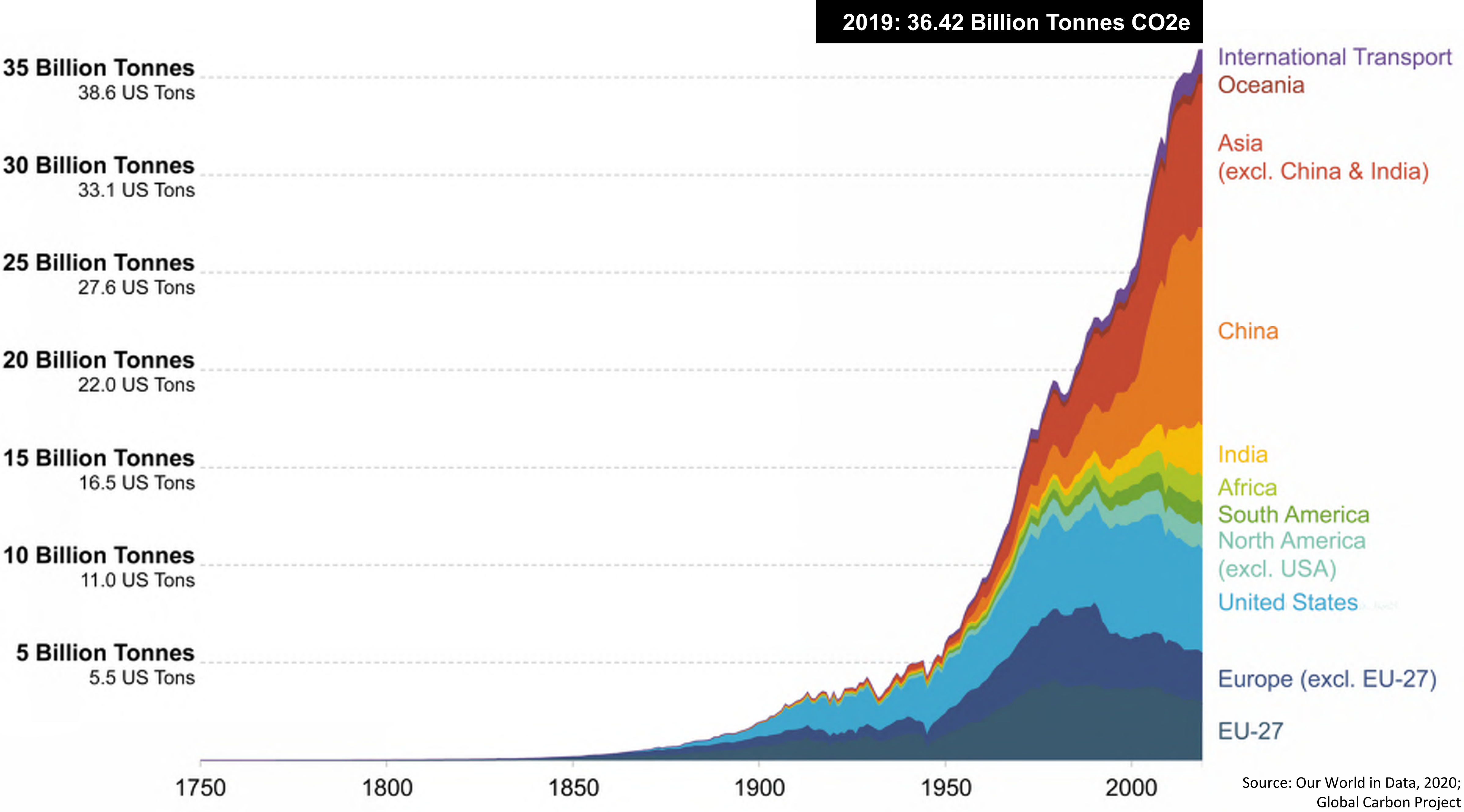
Part 4: Role of building product disclosures

Part 5: Gauging total carbon intensity

1

Global context on carbon emissions

The world is on a carbon binge.



Source: Our World in Data, 2020;
Global Carbon Project

China	10.17 B
Asia (excl. China & India)	7.45 B
United States	5.28 B
EU-27	2.92 B
India	2.62 B
Europe (excl. EU-27)	2.54 B
Africa	1.43 B
International Transport	1.26 B
North America (excl. USA)	1.19 B
South America	1.09 B
Oceania	0.47 B

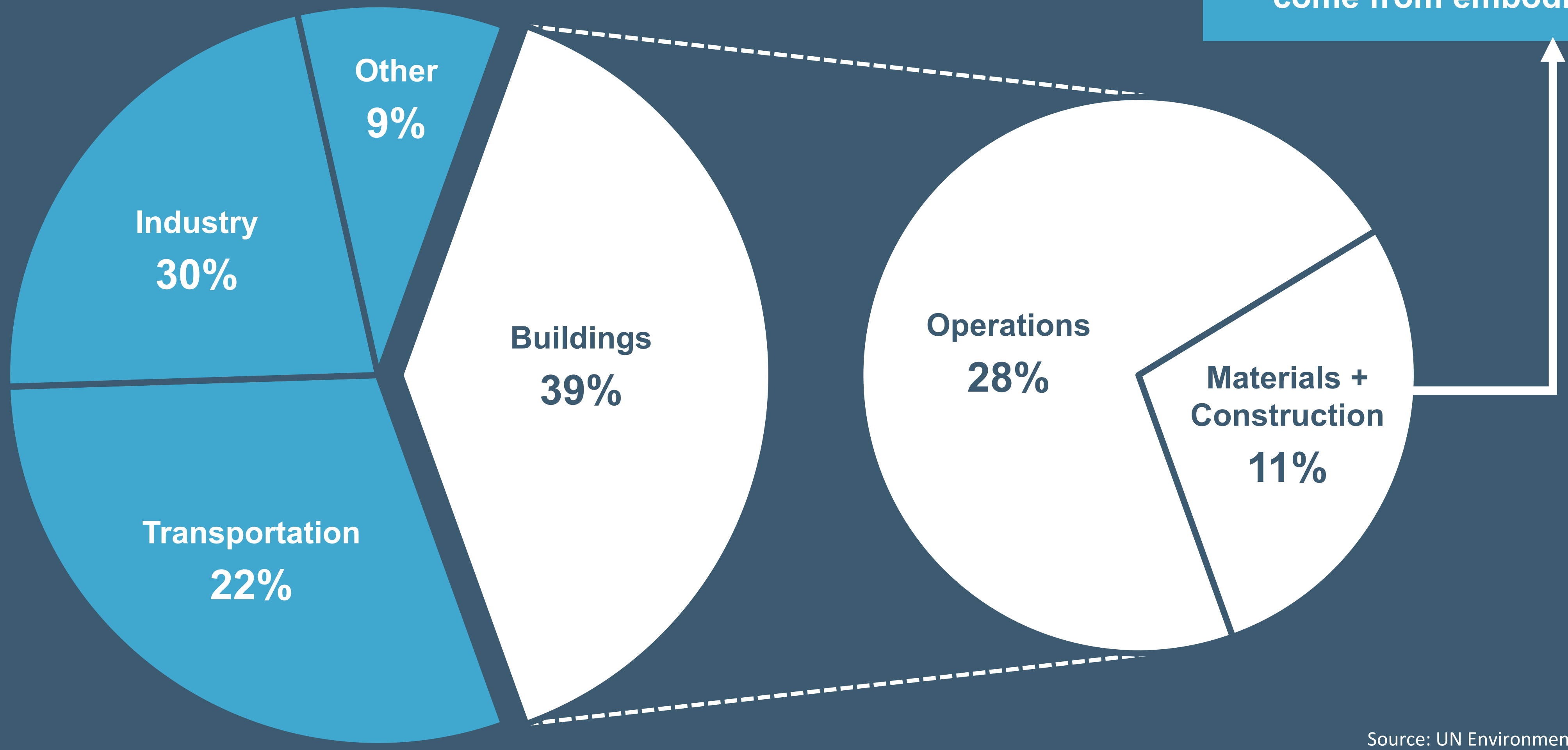
36.42 Billion Tonnes CO_2 / Year

Source: Our World in Data, 2020;
Global Carbon Project

Global CO_2 Emissions by Sector

4.0 Billion Tonnes

of annual global carbon emissions come from embodied carbon



Source: UN Environment Global Status Report 2017;
EIA International Energy Outlook 2017

Projected average annual new construction globally:

65.98 Billion SF / year = 4.0 Billion Tonnes of CO2

Image source: Autodesk

Let us take a closer look at U.S. figures.

Operational carbon:
1.48 B
Tonnes CO2

Embodied carbon:
0.58 B
Tonnes CO2

Global Carbon Projection: U.S. = 5.28 Billion Tonnes CO2 (2019)

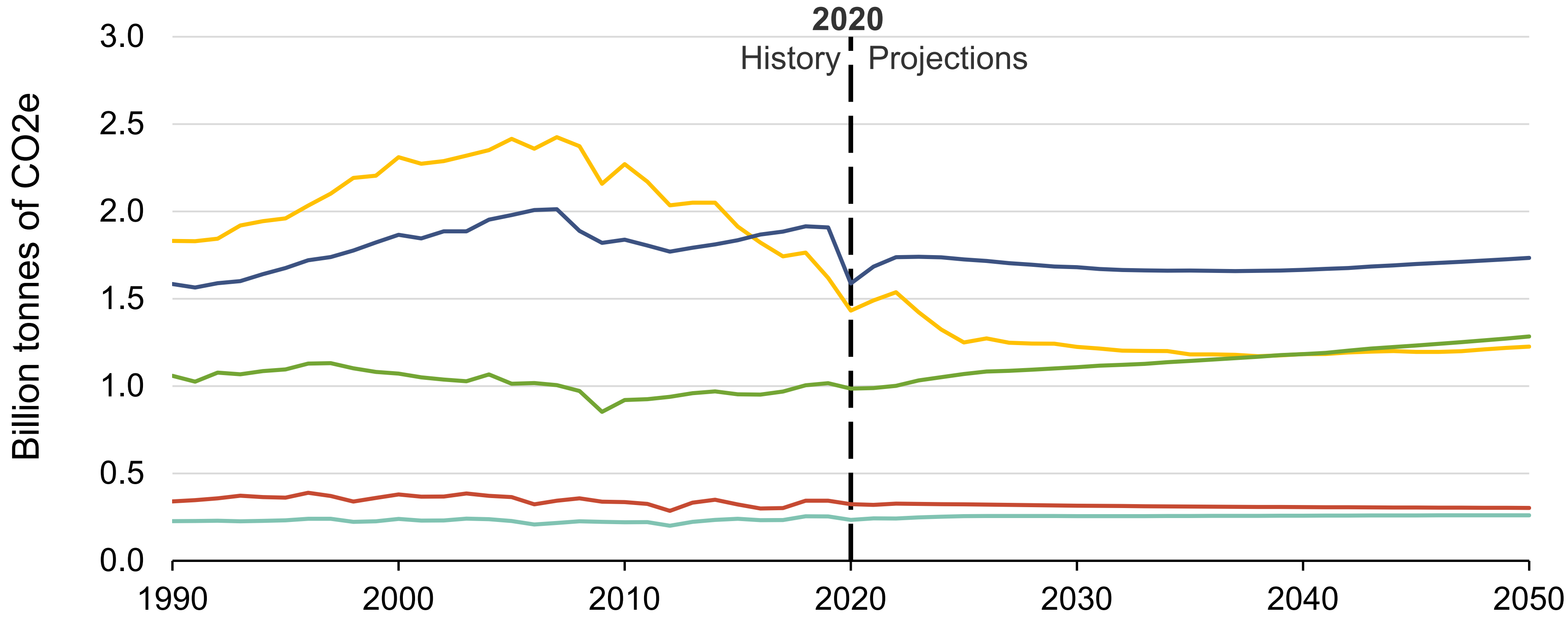
U.S. Energy-Related CO2 Emissions

Global Carbon Project:
US = 5.28 Billion Tonnes (2019)

Energy Information Administration:
US = 5.09 Billion Tonnes (2019)

Energy-related carbon dioxide emissions

EIA AEO2021 reference case



Transportation 1.6 B

Electrical Power 1.4 B

Industrial 1.0 B

Residential 0.3 B

Commercial 0.2 B

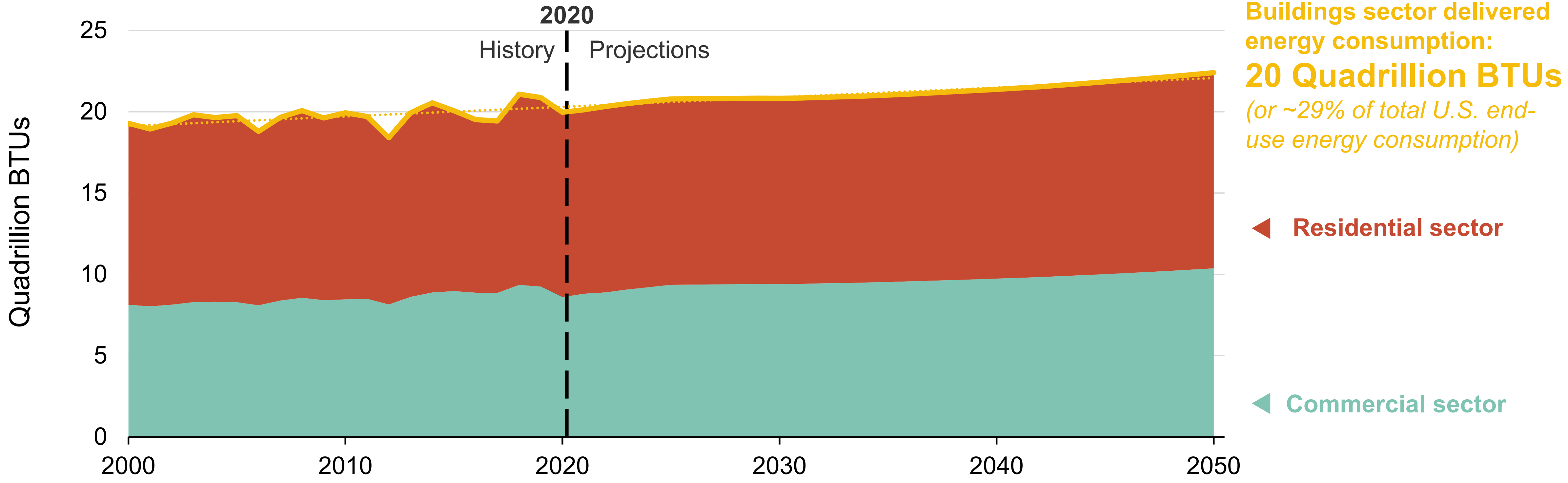
4.5 Billion Tonnes CO2 (in 2020)

Source: U.S. Energy Information Administration

U.S. Buildings Sector Delivered Energy Consumption

Buildings delivered energy consumptions

EIA AEO2021 reference case

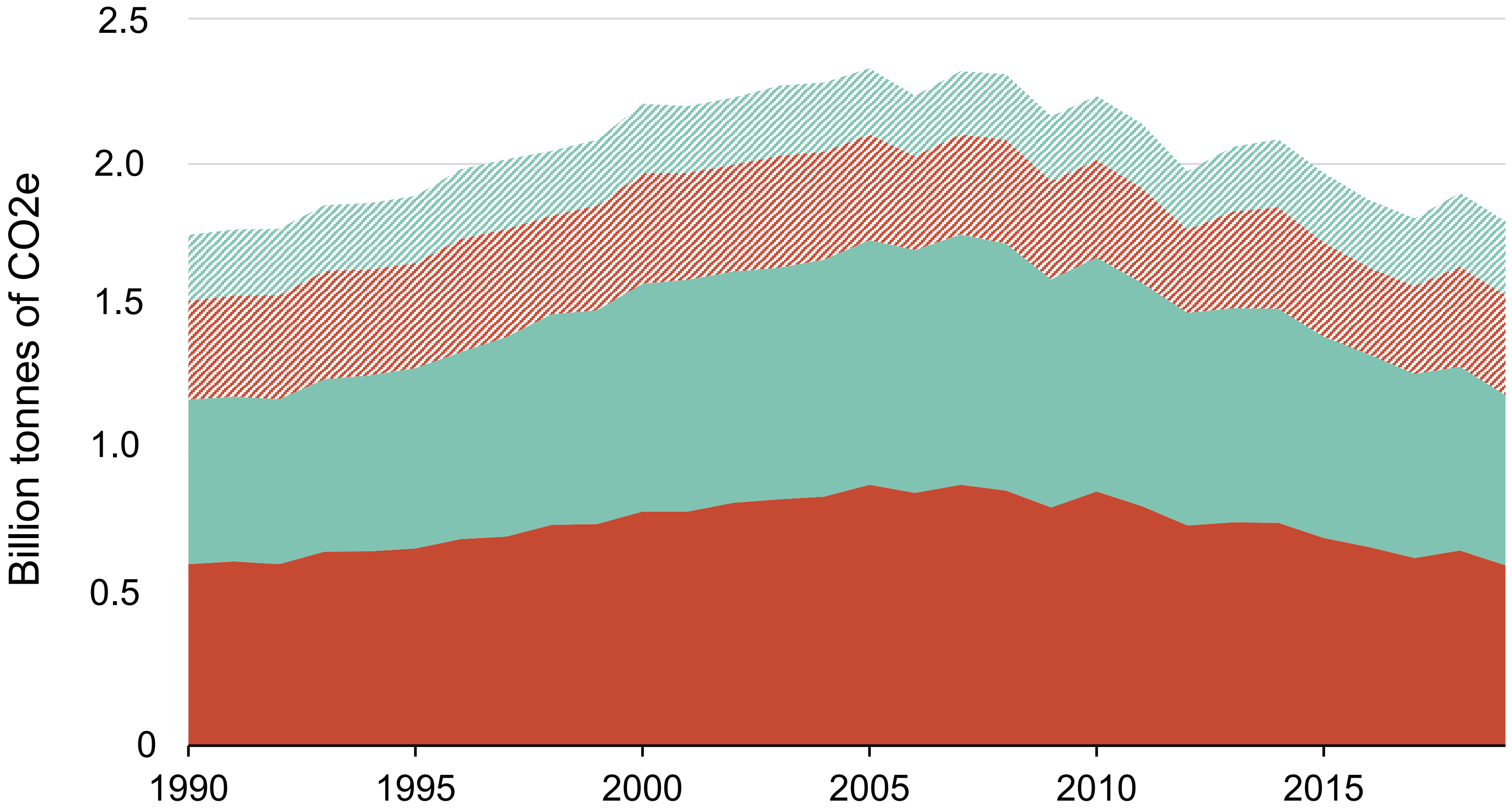


Source: U.S. Energy Information Administration

U.S. Buildings Sector Energy-Related CO2 Emission

Historic data: 1990-2019

In 2019, the buildings sector accounted for approximately **35%** of U.S. carbon emissions.



Commercial Direct Use	0.25 B
Residential Direct Use	0.34 B
Commercial Purchased Elec.	0.59 B
Residential Purchased Elec.	0.62 B

1.80 Billion Tonnes CO2 (2019)
(vs. 1.48 Billion via Global Carbon Project)

Source: U.S. Energy Information Administration

2

Defining embodied carbon for buildings

Scope

Stages

Define the Scope

The scope can make a huge difference in the total embodied carbon figures.

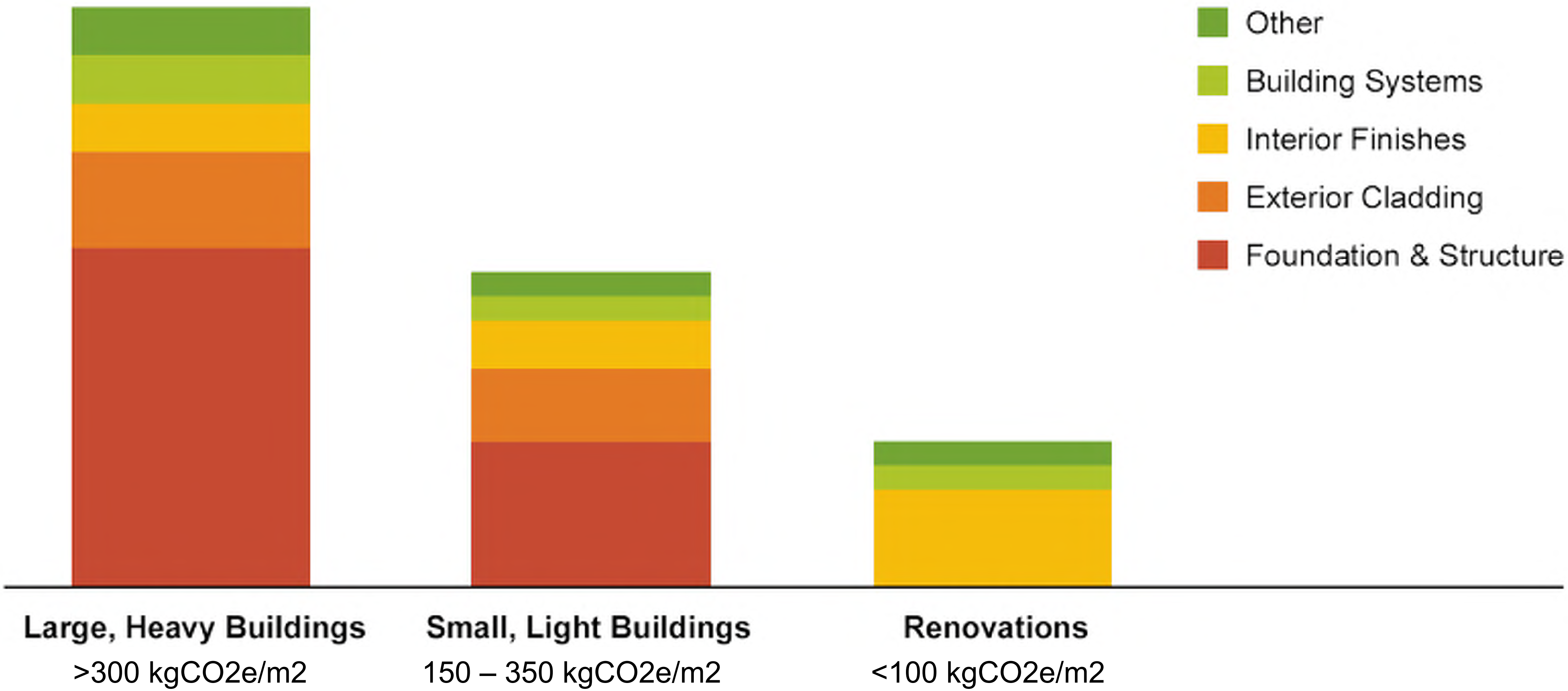
When it comes to defining embodied carbon on a building project, design teams should clarify the scope of the assessment. Which of the following does the scope include?

- Substructure
- Superstructure
- Enclosure
- Interiors
- Others (e.g. mechanical systems)

A new multi-story commercial building is going to be responsible for much more embodied carbon than a renovation project of the same magnitude.

The LEED Gold IU Eskenazi Museum renovation reused over 95% of the existing walls, floor, and roof components. Image source: Indiana University

Carbon Emissions by Building Type and Materials



Adapted from: Larry Strain, “Time Value of Carbon” (2017)

Source: Browning Day

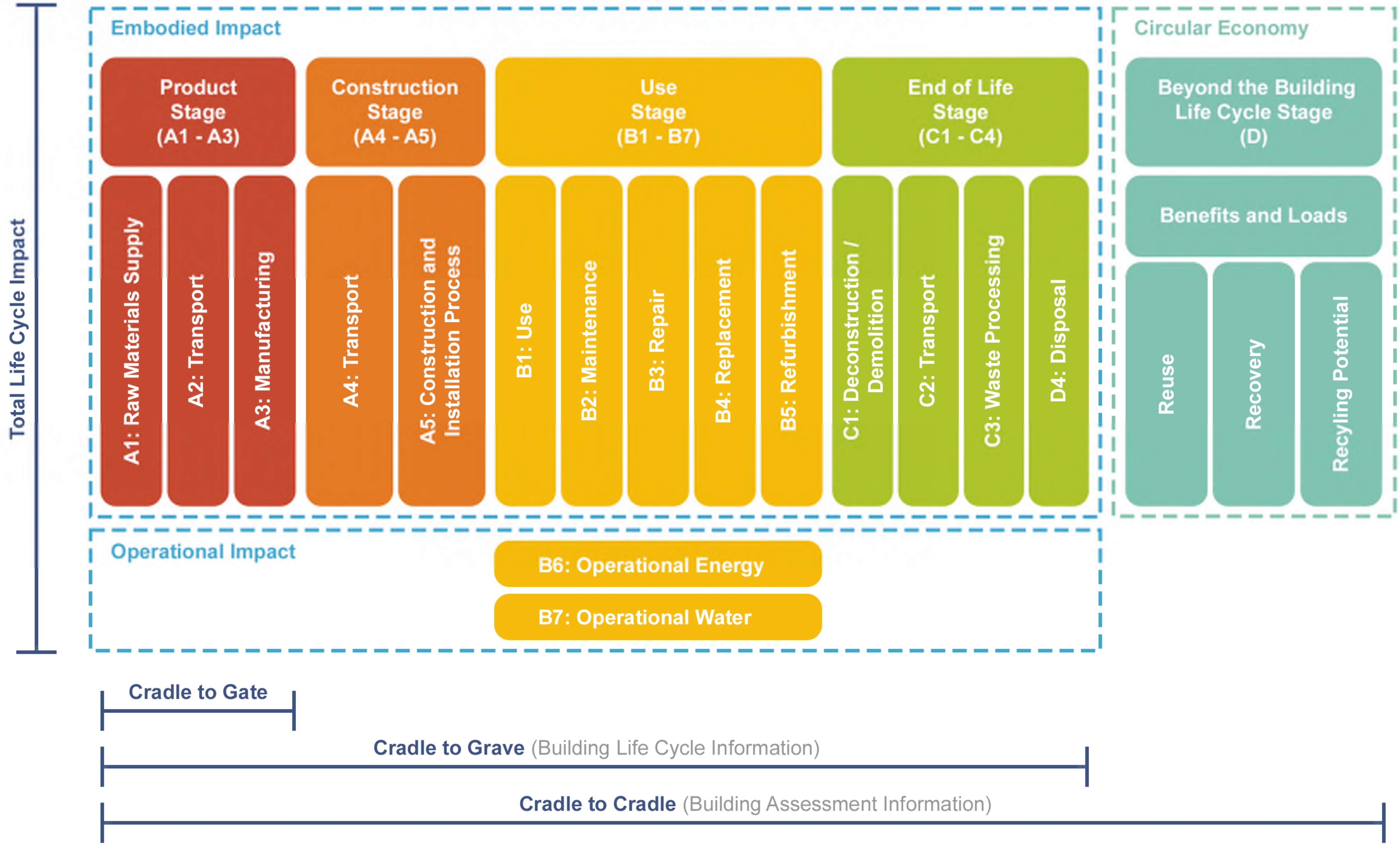
Define the Stages

Not all lifecycle assessments cover the same stages.

Standard EN 15978:2011: *Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method* was developed by the European Committee for Standardization (CEN).

This document defines a calculation method, based on LCA and other quantified environmental information, to assess the environmental performance of a building.

Source: Browning Day



Total Life Cycle Impact
Embodied Impact
Product Stage (A1 - A3)
Construction Stage (A4 - A5)
Use Stage (B1 - B7)
End of Life Stage (C1 - C4)
A1: Raw Materials Supply
A2: Transport
A3: Manufacturing
A4: Transport
A5: Construction and Installation Process
B1: Use
B2: Maintenance
B3: Repair
B4: Replacement
B5: Refurbishment
C1: Deconstruction / Demolition
C2: Transport
C3: Waste Processing
D4: Disposal
Circular Economy
Beyond the Building Life Cycle Stage (D)
Benefits and Loads
Reuse
Recovery
Recyling Potential
Operational Impact
B6: Operational Energy
B7: Operational Water
Cradle to Gate
Cradle to Grave (Building Life Cycle Information)
Cradle to Cradle (Building Assessment Information)

100
kg CO_2e / m^2

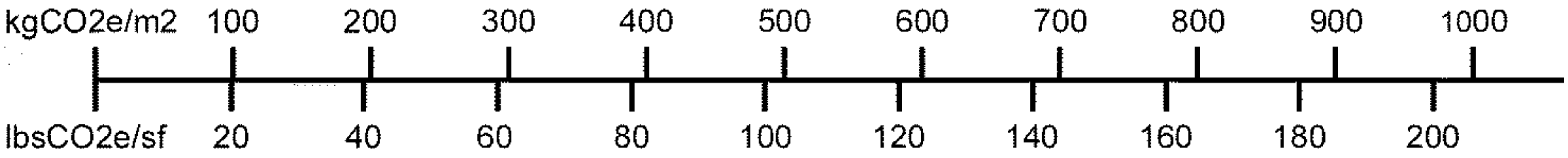
kilograms of carbon dioxide equivalent emissions per square meter

Becoming the industry's standard unit.

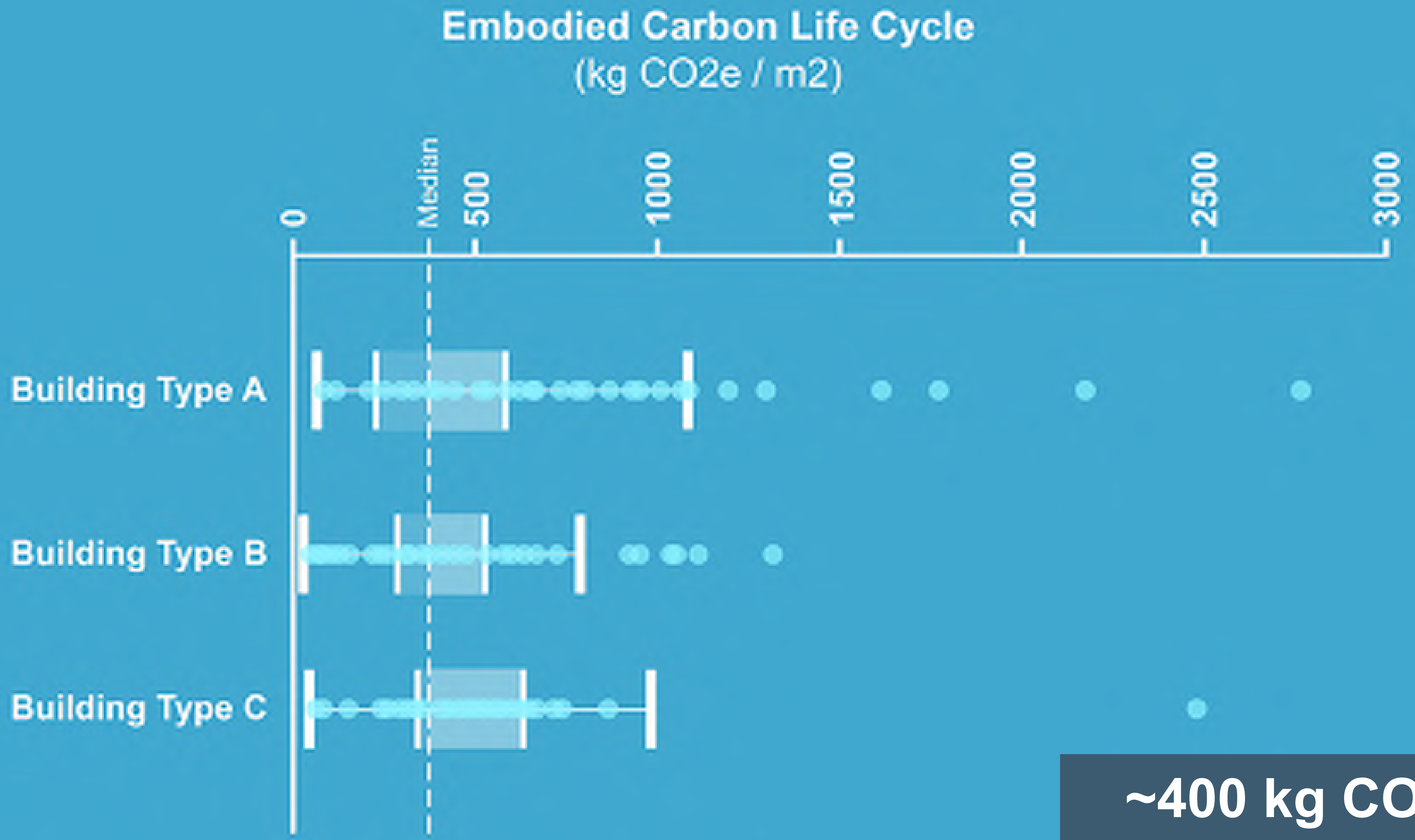
=

20.48
lbs CO_2e / ft^2

pounds of carbon dioxide equivalent emissions per square foot



Source: Browning Day



~400 kg CO_2e / m^2

Median per CLF's Embodied Carbon Benchmarking Study

Case Study: IUPUI Innovation Hall

Case Study

IUPUI Innovation Hall

Indianapolis, Indiana

Gross area: 101,900 sf.

Multidisciplinary research classroom facility on the Indianapolis campus.

Tracking LEED v4 Gold.

24% energy improvement over baseline.

Energy conservation measures include:

- Filtered fume hood analysis / optimization
- HVAC Energy Use reduction
- Water Use savings
- Lighting power density reduction
- Daylighting

Embodied

499

kgCO2e/m2

Operational

275

kgCO2e/m2
year

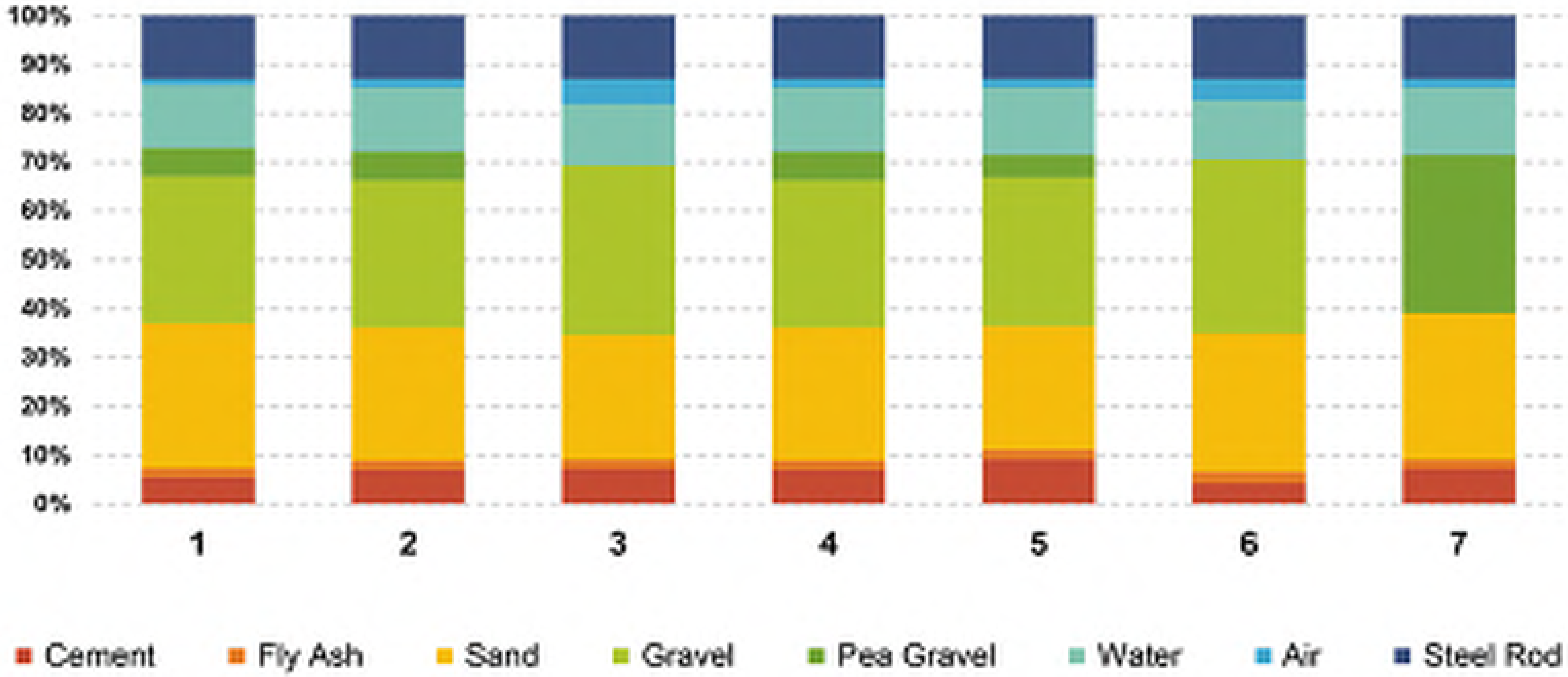
Source: IUPUI

Structural Cast-In-Place Concrete:
Steel Reinforced Non-Air-Entrained Lean Mix Summaries

Mix Number	1	2	3	4	5	6	7
28-Day Strength	3000 psi	4000 psi	4000 psi	4000 psi	6000 psi	2000 psi	4000 psi
Components (cf)							
Cement	1.68	2.19	2.24	2.19	2.87	1.32	2.24
Fly Ash	0.60	0.60	0.60	0.60	0.60	0.72	0.60
Sand	9.18	8.43	7.89	8.43	7.83	8.81	9.29
Gravel	9.34	9.34	10.75	9.34	9.41	11.03	0.00
Pea Gravel	1.81	1.84	0.00	1.84	1.47	0.00	10.03
Water	3.99	4.07	3.89	4.07	4.28	3.77	4.30
Air	0.41	0.54	1.62	0.54	0.54	1.35	0.54
Steel Rod	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Total	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**	**31.00**

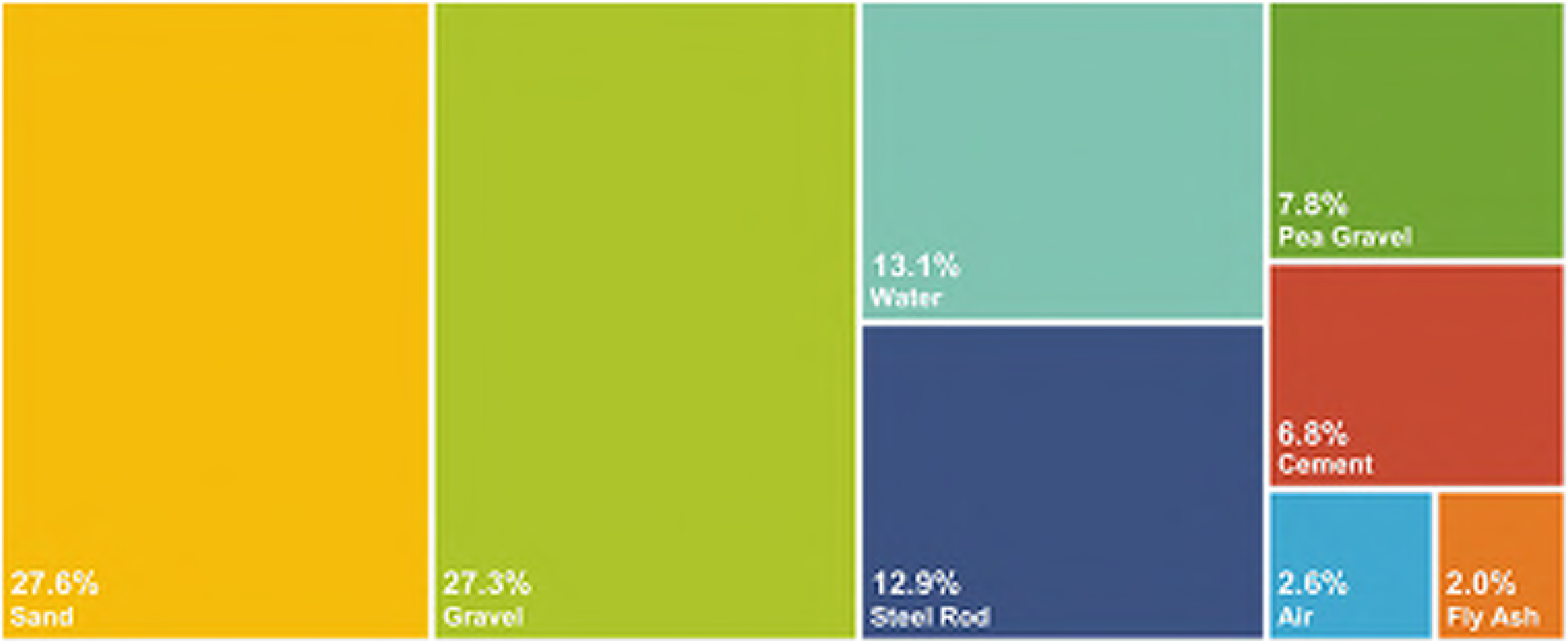
Source: Browning Day

Structural Cast-In-Place Concrete: Components By Proportion Per Mix



Source: Browning Day

Structural Cast-In-Place Concrete: Mix Components Treemap, Average Proportions



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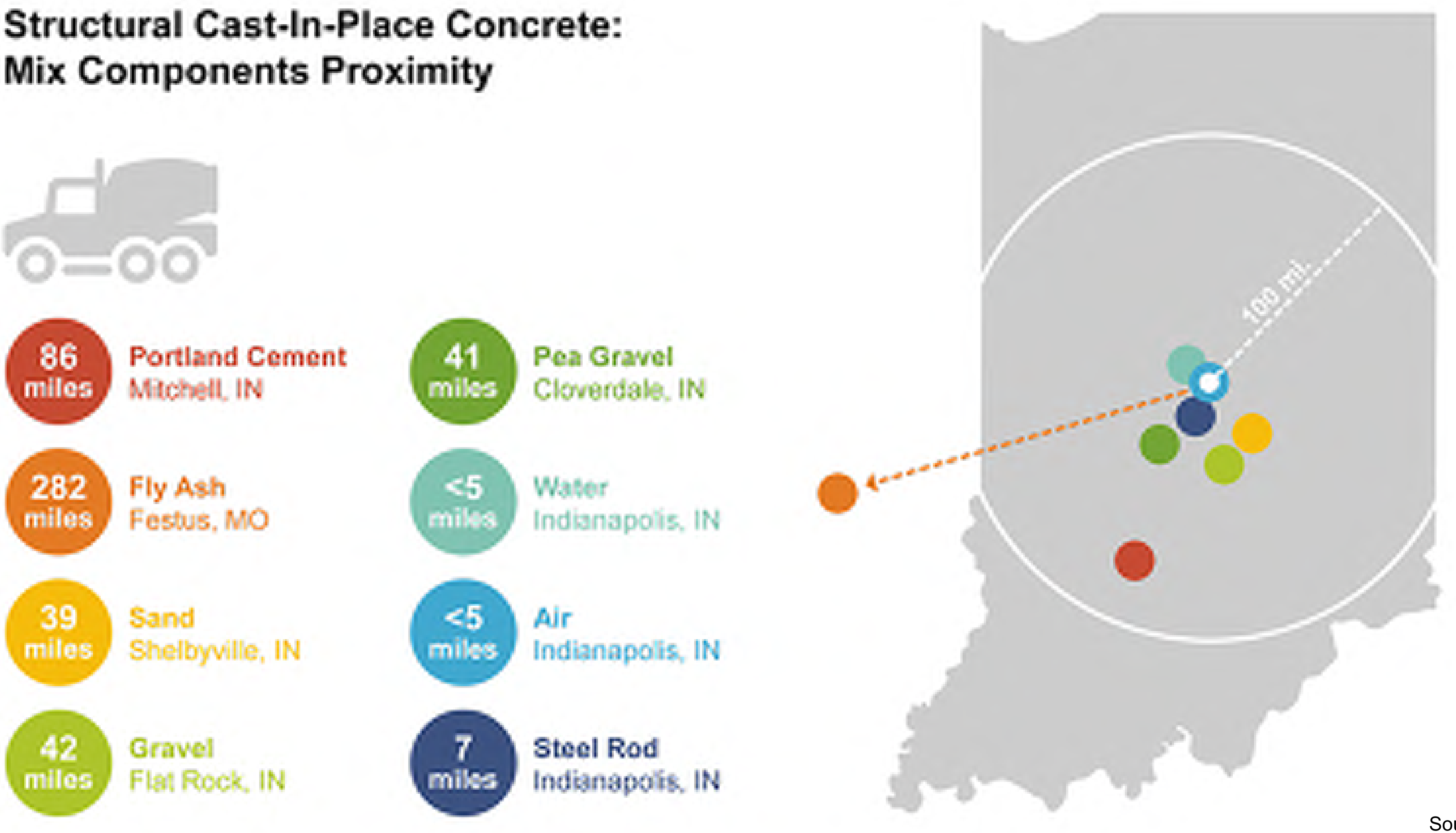
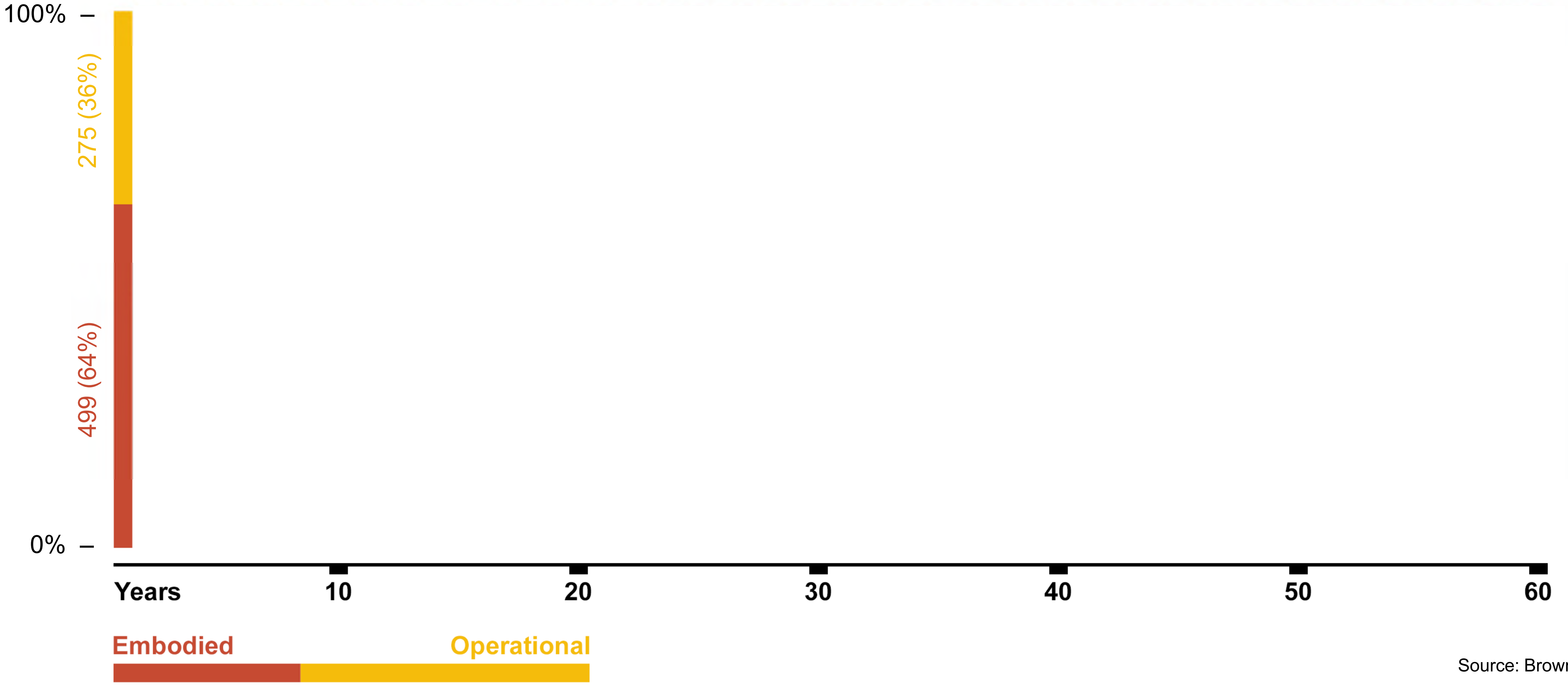


Source: Browning Day

Embodied vs Cumulative Operational Carbon Impact by Year

Embodied carbon figures only account for the building's structure and envelope.
Figure assumes the same average energy consumption every year.
Maintenance not included.



Source: Browning Day

IUPUI Innovation Hall

Our embodied carbon data painted an incomplete picture.

1. Embodied carbon only accounts for structure and exterior cladding.
2. Interior fit out and mechanical systems likely to be renovated over time.
3. Operational carbon does not account for the greening of the utility grid.

Source: IUPUI

Modeling and measuring embodied carbon

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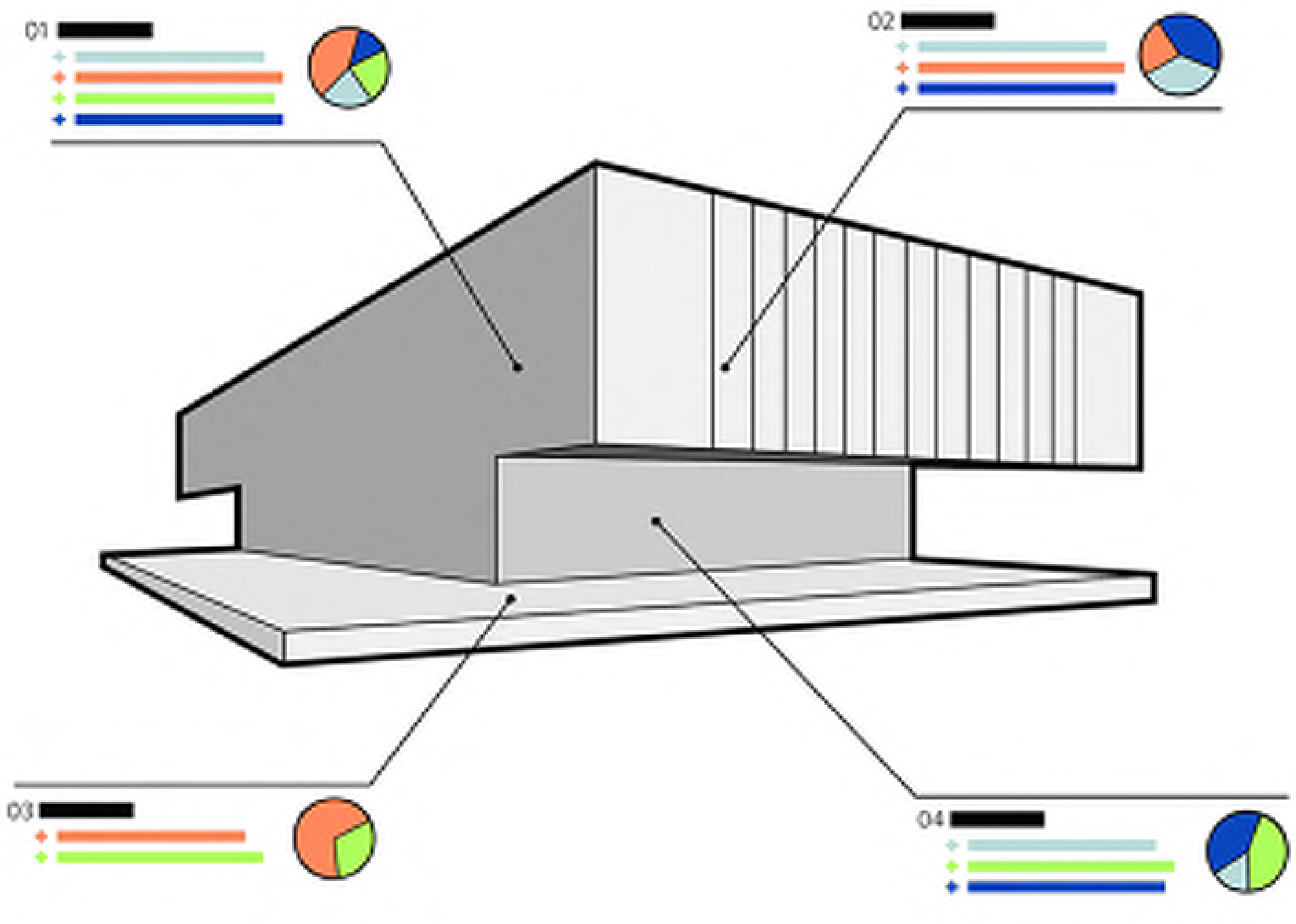
Modeling and Measuring Embodied Carbon

We can now leverage building information modeling (BIM) and other modeling tools to conduct environmental impact assessments on whole buildings.

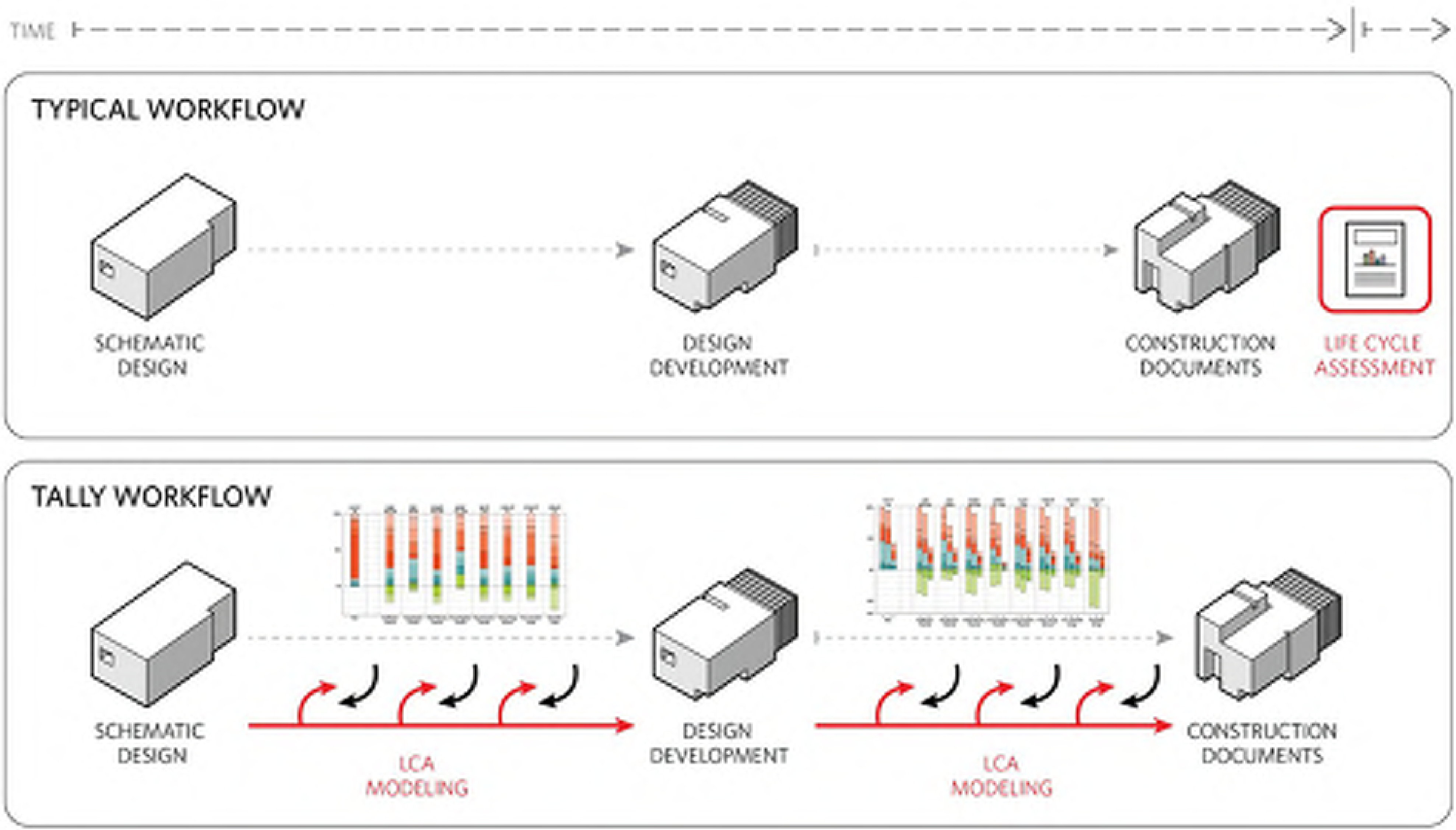
These tools tap into industry-wide datasets.

The AIA Design Data Exchange (DDx) now allows 2030 Commitment signatories to record and track embodied carbon figures from the following tools:

- Athena
- Tally
- EC3
- OneClick LCA
- eTool



Source: Kieran Timberlake



Source: Kieran Timberlake

LEED and Embodied Carbon

LEED v4 BD+C: Building life-cycle impact reduction

Option 4. whole-building life-cycle assessment (3 points)

For new construction (buildings or portions of buildings), conduct a life-cycle assessment of the project's structure and enclosure that demonstrates a minimum of 10% reduction, compared with a baseline building, in at least three of the six impact categories listed below, one of which must be global warming potential.

No impact category assessed as part of the life-cycle assessment may increase by more than 5% compared with the baseline building.

Under **LEED v4.1 BD+C** project teams can get 1 point just for running the LCA model (to encourage more modeling).

Source: USGBC

Case Study: IPL Eagle Branch Library

Case Study

IPL Eagle Branch Library

Indianapolis, Indiana

Gross area: 18,663 sf.

Branch of the Indianapolis Public Library.

LEED v4 Gold certified.

50% energy improvement over baseline.

Energy-efficiency with on-site renewable energy combined for a predicted energy cost savings of over 80%.

Envelope and structure were optimized to reduce the building's embodied carbon by over 15%.

Through efficient fixtures and fittings, the Eagle Branch reduced indoor water consumption by nearly 35%.

Nearly 63% of construction waste was diverted from landfill.

Embodied

412

$kgCO_2e/m^2$

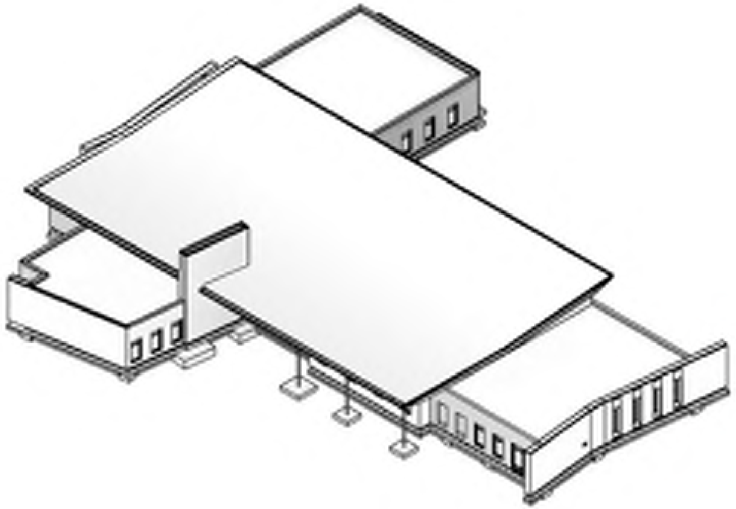
Operational

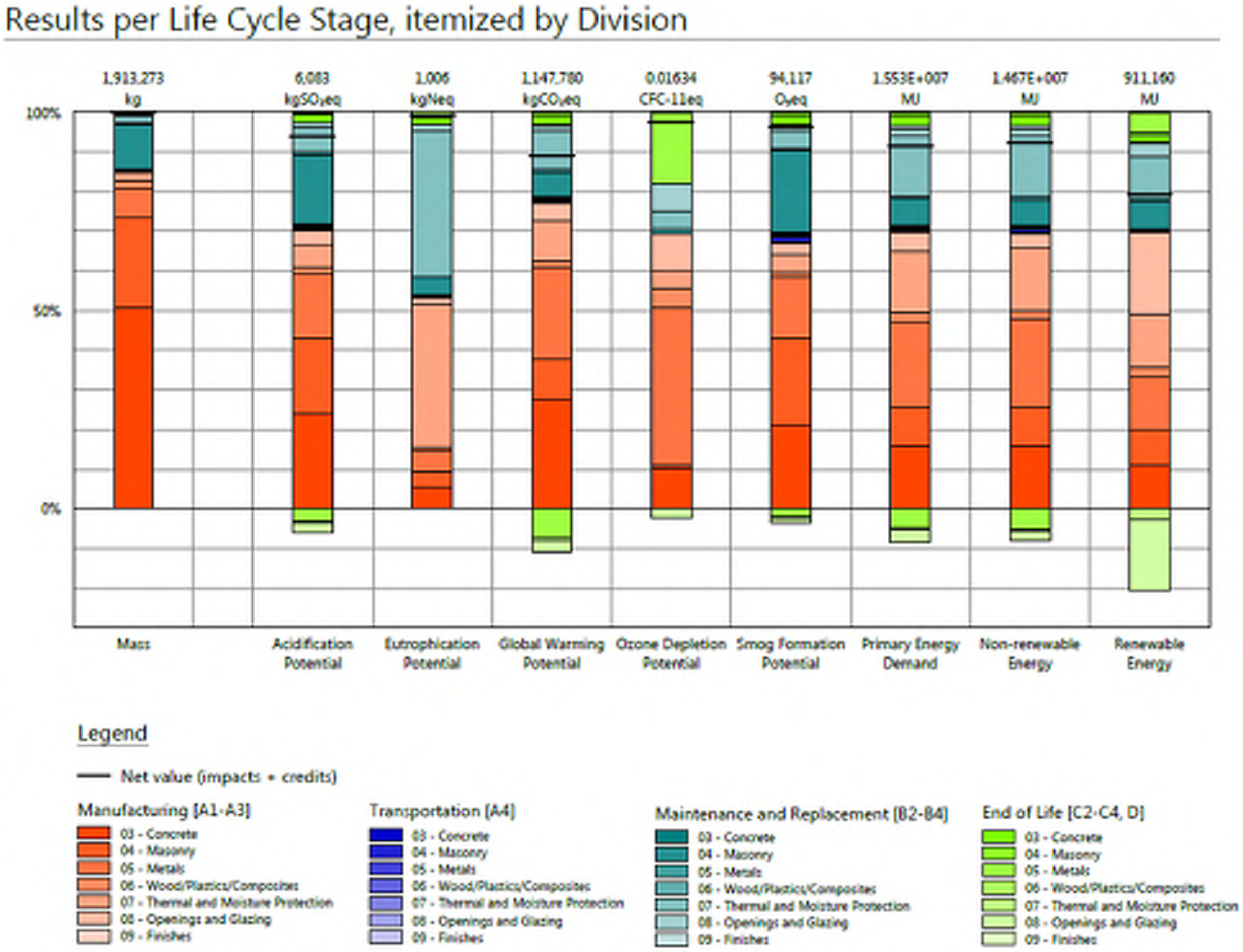
33

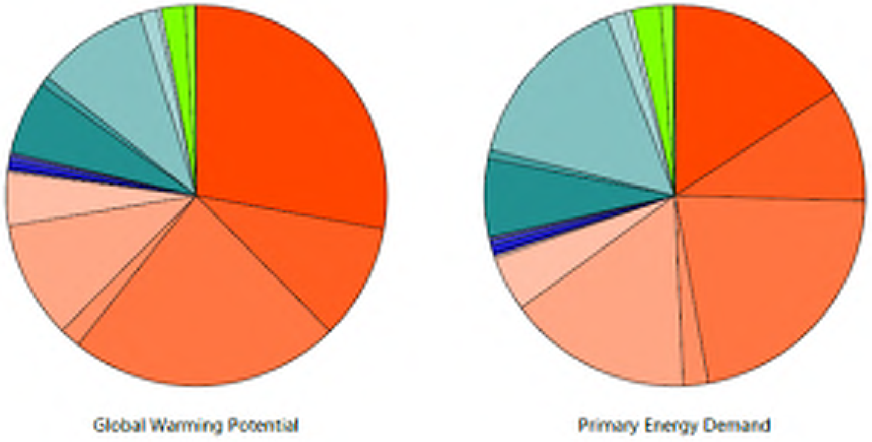
$kgCO_2e/m^2$ year

Source: Browning Day

Source: Browning Day

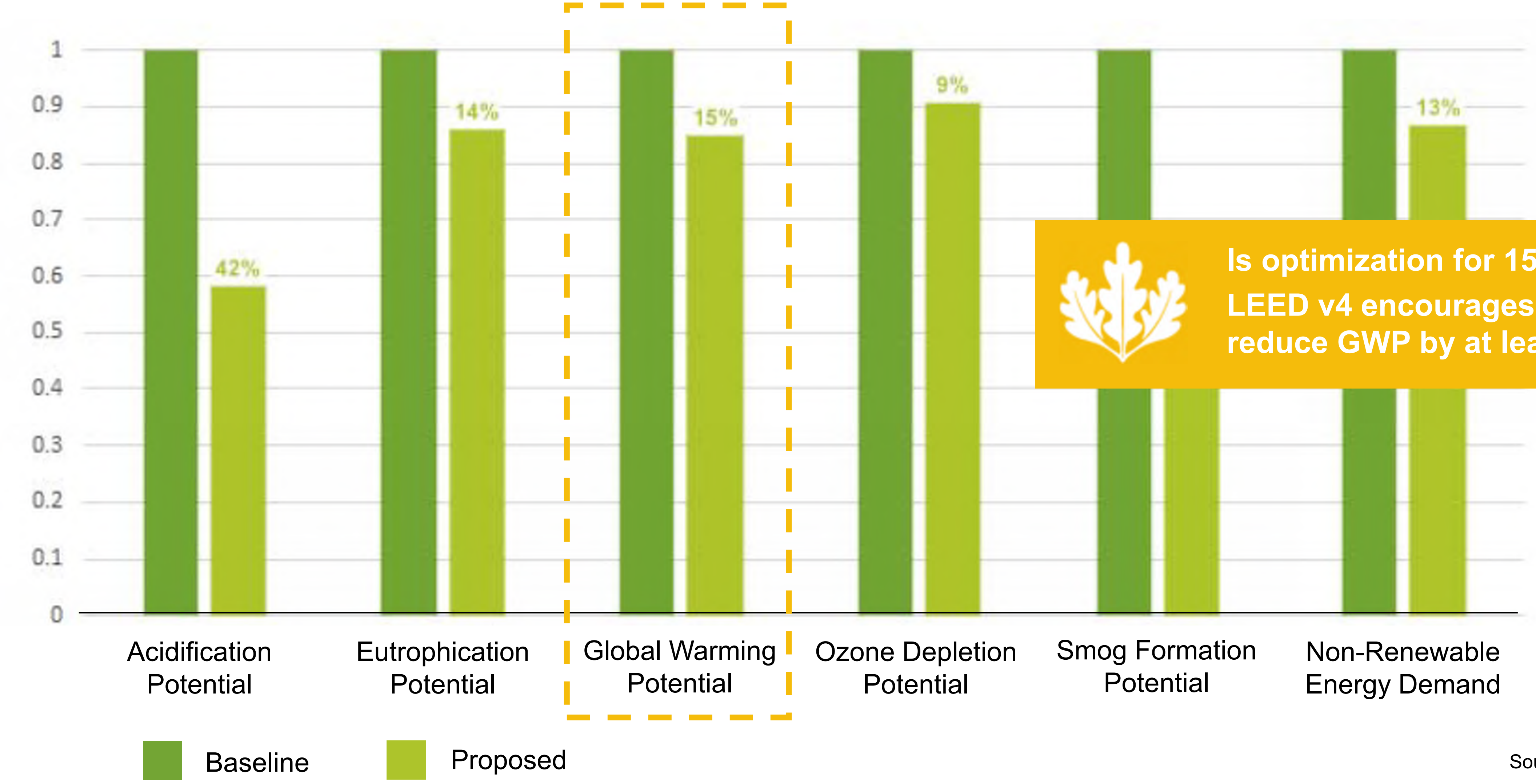






Source: Browning Day

Life-Cycle Assessment: Baseline vs Proposed



Is optimization for 15% good?
LEED v4 encourages teams to reduce GWP by at least 10%.

Source: Browning Day

IPL Eagle Branch Library

Baseline embodied carbon:

486 kgCO2e/m2

Proposed embodied carbon:

412 kgCO2e/m2 (15% reduction)

Embodied carbon optimization measures:

- Added fly ash content to concrete.
- Reduced cantilever / structural steel.
- Reduced curtainwall system areas (good for operational carbon too).
- Changed XPS and fiberglass batt to mineral wool.
- Supplanted some limestone for brick.

Source: Browning Day

Case Study: Infosys Training Center

Case Study

Infosys Training Center

Indianapolis, Indiana

Gross area: 160,585 sf.

Corporate headquarters and training center.

Tracking LEED v4 Platinum.

24% energy improvement over baseline.

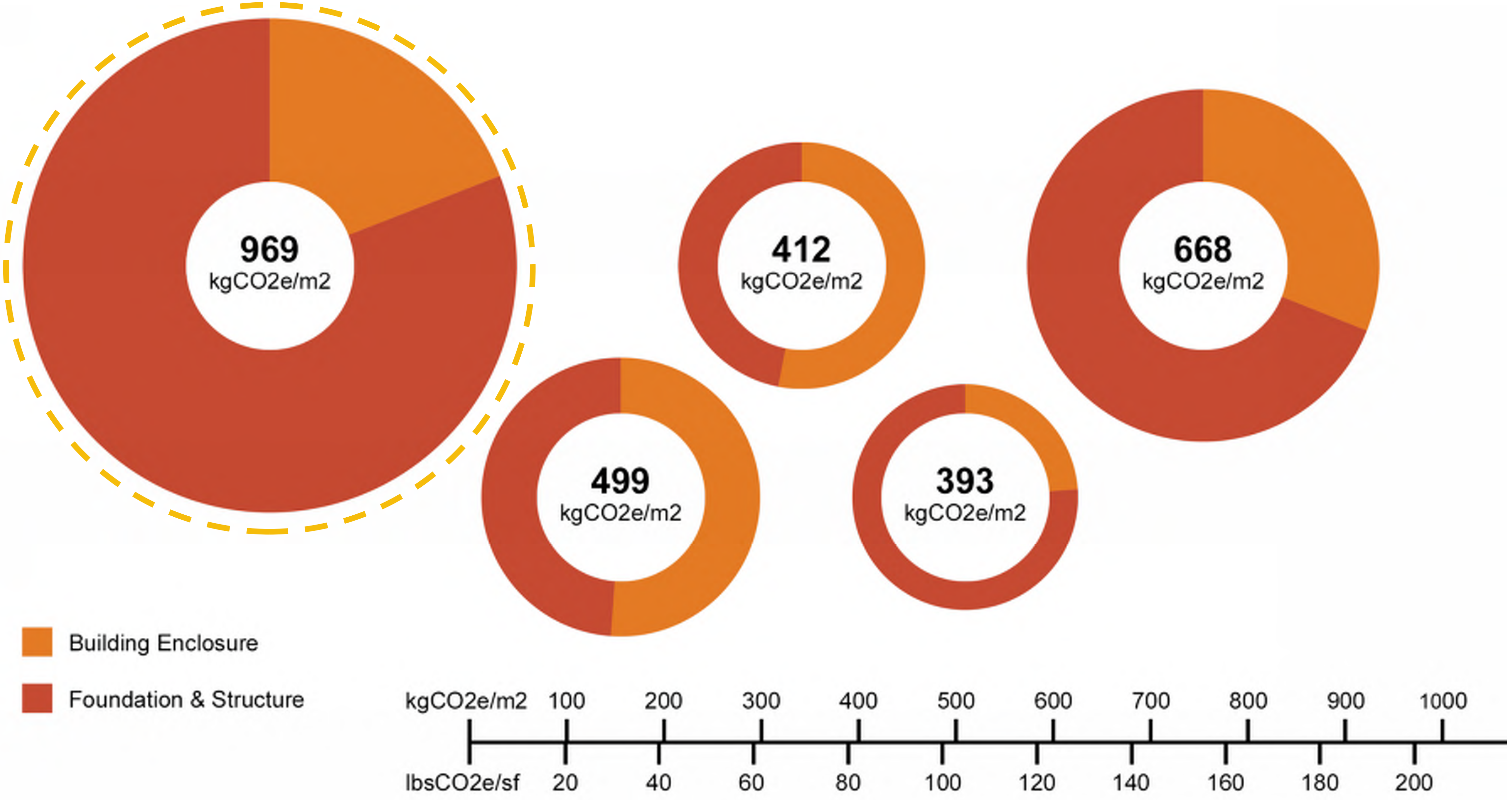
400kW on-site photovoltaic system to offset $75,000 / year in energy costs.

Energy conservation measures include:

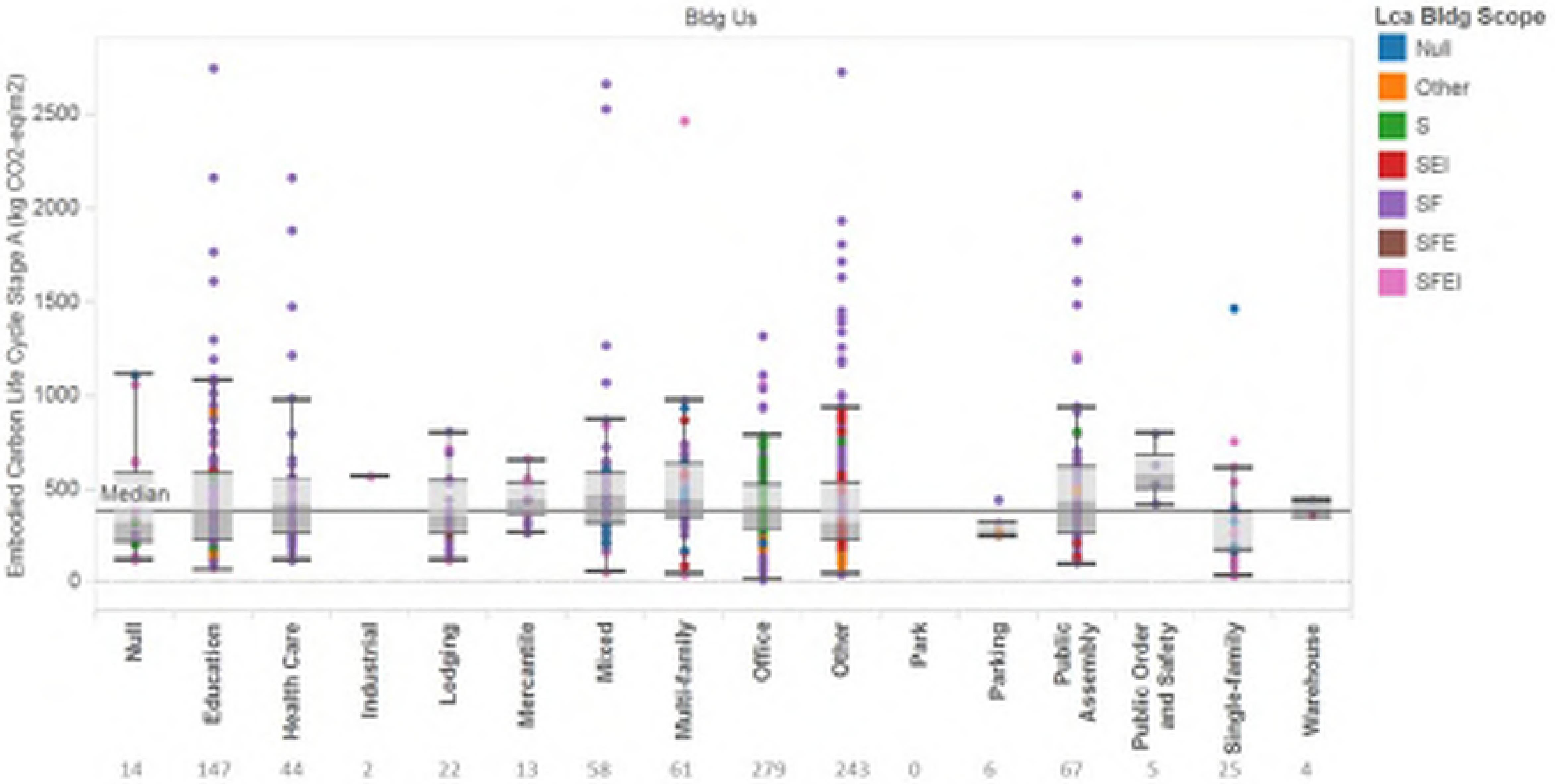
- Optimized envelope solutions.
- High-efficiency mechanicals.
- Daylight / lighting optimization.

Project reveals the embodied carbon intensity of “heavy” structures.

Source: Browning Day



Source: Browning Day



Source: University of Washington

Role of building product disclosures

4

Environmental Product Declarations

Product transparency documents.

Lots of them:

- Environmental Product Declarations (EPDs).
- Declare label.
- Health Product Declarations.
- Etc.

But extremely difficult to compare products for optimization with regard to environmental / human health impacts.

EPDs are a premiere source for embodied carbon information for specific building products.

Think of EPDs like nutrition labels on food.

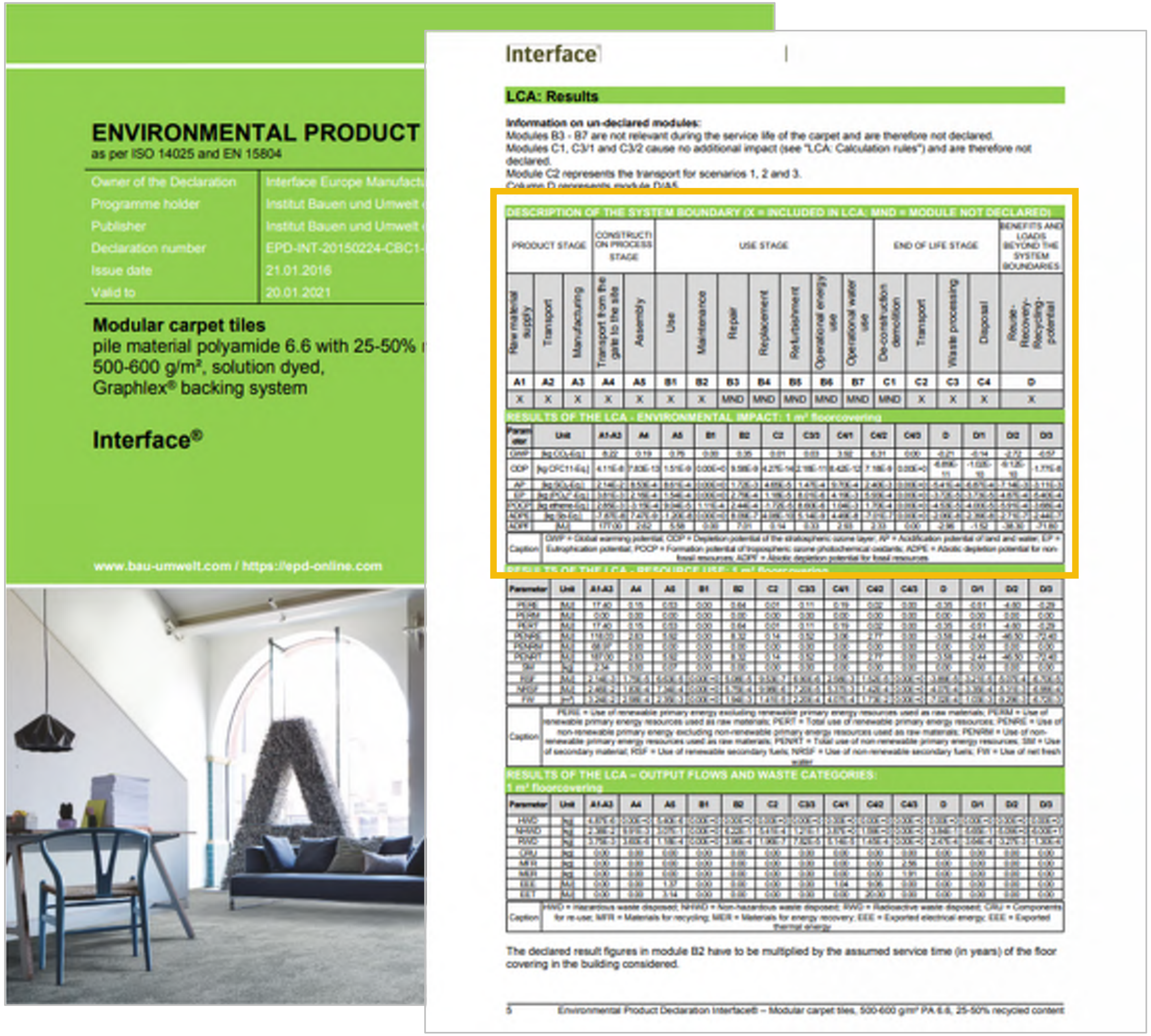
Product Impacts

Declared Unit: 1 m^3 of 10,000 psi concrete at 28 days

Amount Per Declared Unit

Global Warming Potential	445 $kgCO_2eq$
Emitted	460 $kgCO_2eq$
Sequestered	-15 $kgCO_2eq$
Ozone Depletion	0.000 kgCFC11eq
Acidification	2.96 $kgSO_2eq$
Eutrophication	0.09 kgNeq
Smog Formation	0.61 kgO_3eq
Primary Energy Demand	3017 MJ
Non-renewable	3000 MJ
Renewable	17 MJ

Source: University of Washington



LEED v4 BD+C: Building product disclosure and optimization - environmental product declarations

Product-Specific EPD (no PCR)

- **1/4 product**

Industry-Wide (Generic) EPD

- **1/2 product**

Product-Specific Type III EPD

- **1 product**

Source: Interface

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	X	X	MND	MND	MND	MND	MND	MND	X	X	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 m² floorcovering

Parameter	Unit	A1-A3	A4	A5	B1	B2	C2	C3/3	C4/1	C4/2	C4/3	D	D/1	D/2	D/3
GWP	[kg CO_2-Eq.]	8.22	0.19	0.76	0.00	0.35	0.01	0.03	3.92	6.31	0.00	-0.21	-0.14	-2.72	-0.57
ODP	[kg CFC11-Eq.]	4.11E-8	7.83E-13	1.51E-9	0.00E+0	9.58E-9	4.27E-14	2.18E-11	8.42E-12	7.18E-9	0.00E+0	-6.89E-11	-1.02E-10	-9.12E-10	-1.77E-8
AP	[kg SO_2-Eq.]	2.14E-2	8.53E-4	8.61E-4	0.00E+0	1.72E-3	4.65E-5	1.47E-4	9.70E-4	2.40E-3	0.00E+0	-5.41E-4	-6.87E-4	-7.14E-3	-3.11E-3
EP	[kg $(PO_4)^{3-}$-Eq.]	3.81E-3	2.16E-4	1.54E-4	0.00E+0	2.79E-4	1.18E-5	8.01E-6	4.19E-3	5.93E-4	0.00E+0	-3.72E-5	-3.73E-5	-4.87E-4	-5.40E-4
POCP	[kg ethene-Eq.]	2.85E-3	-3.15E-4	9.04E-5	1.11E-4	2.44E-4	-1.72E-5	8.60E-6	1.04E-3	1.70E-4	0.00E+0	-4.53E-5	-4.00E-5	-5.91E-4	-3.68E-4
ADPE	[kg Sb-Eq.]	-7.87E-8	7.47E-9	-1.20E-8	0.00E+0	8.09E-7	4.08E-10	5.14E-9	4.49E-8	-7.01E-7	0.00E+0	-2.06E-8	-2.39E-8	-2.71E-7	-2.44E-7
ADPF	[MJ]	177.00	2.62	5.58	0.00	7.01	0.14	0.33	2.93	2.33	0.00	-2.96	-1.52	-38.30	-71.80

Caption	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non-fossil resources; ADPF = Abiotic depletion potential for fossil resources

Source: Interface

Aggregating EPDs into a Project Model

The EC3 Tool could be a game-changer.

The Embodied Carbon in Construction Calculator (EC3) tool.

From the Carbon Leadership Forum (University of Washington).

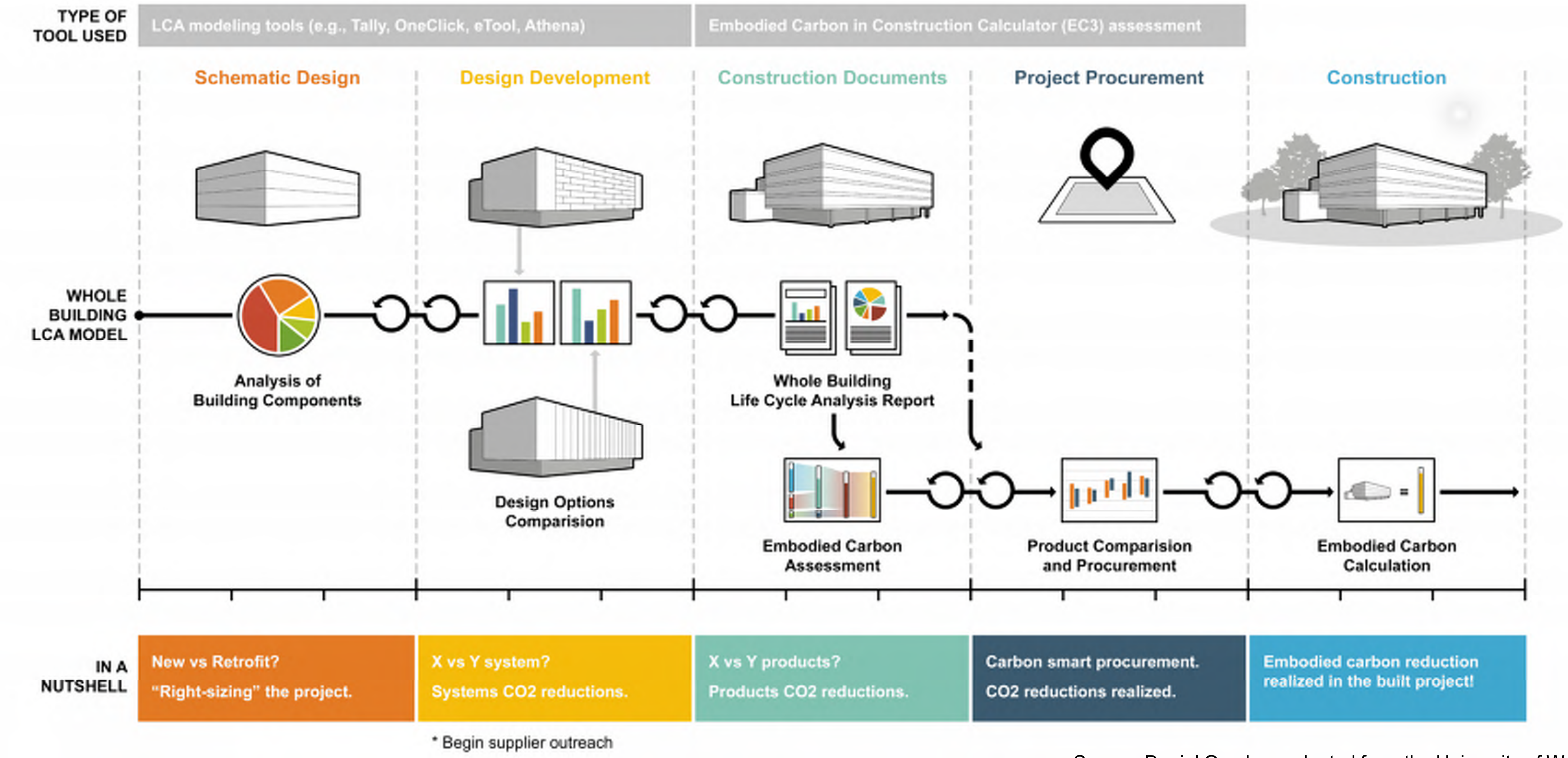
Free and easy-to-use; allows benchmarking, assessment and reductions in embodied carbon.

Allows for supply chain specific analysis of embodied carbon data, utilizing the first searchable and sortable database of all United States and Canadian Environmental Product Declarations (EPDs).

buildingtransparency.org

Source: University of Washington

Whole-Building Embodied Carbon Modeling Workflow



Source: Daniel Overbey, adapted from the University of Washington

Gauging total carbon intensity

5

Shift the conversation to *total carbon intensity*.

Annual U.S. CO2e emissions: ~ 5 B Tonnes

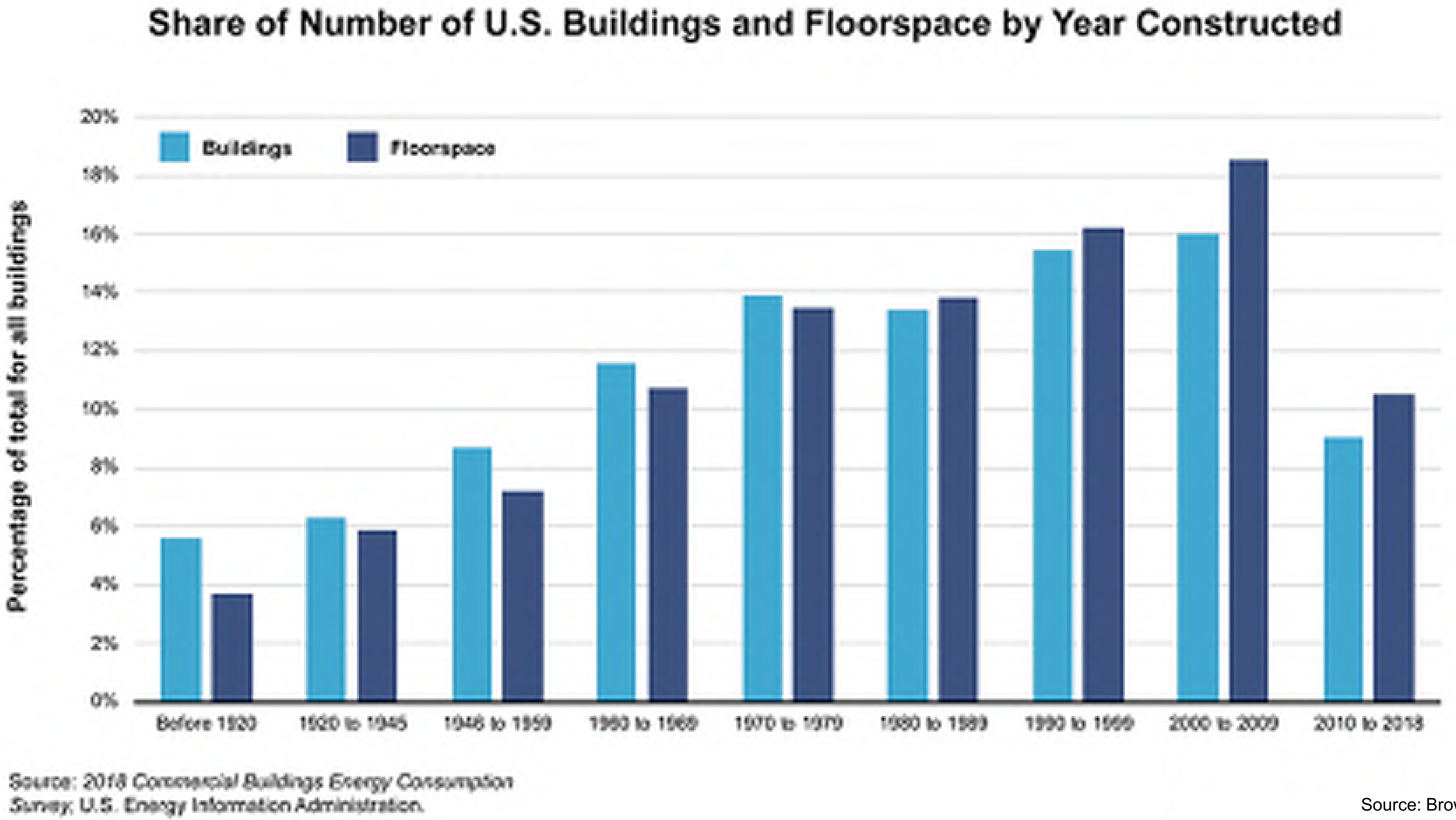
28% operational carbon: 1.4 B Tonnes
11% embodied carbon: 0.6 B Tonnes

Emerging data on embodied carbon suggests:

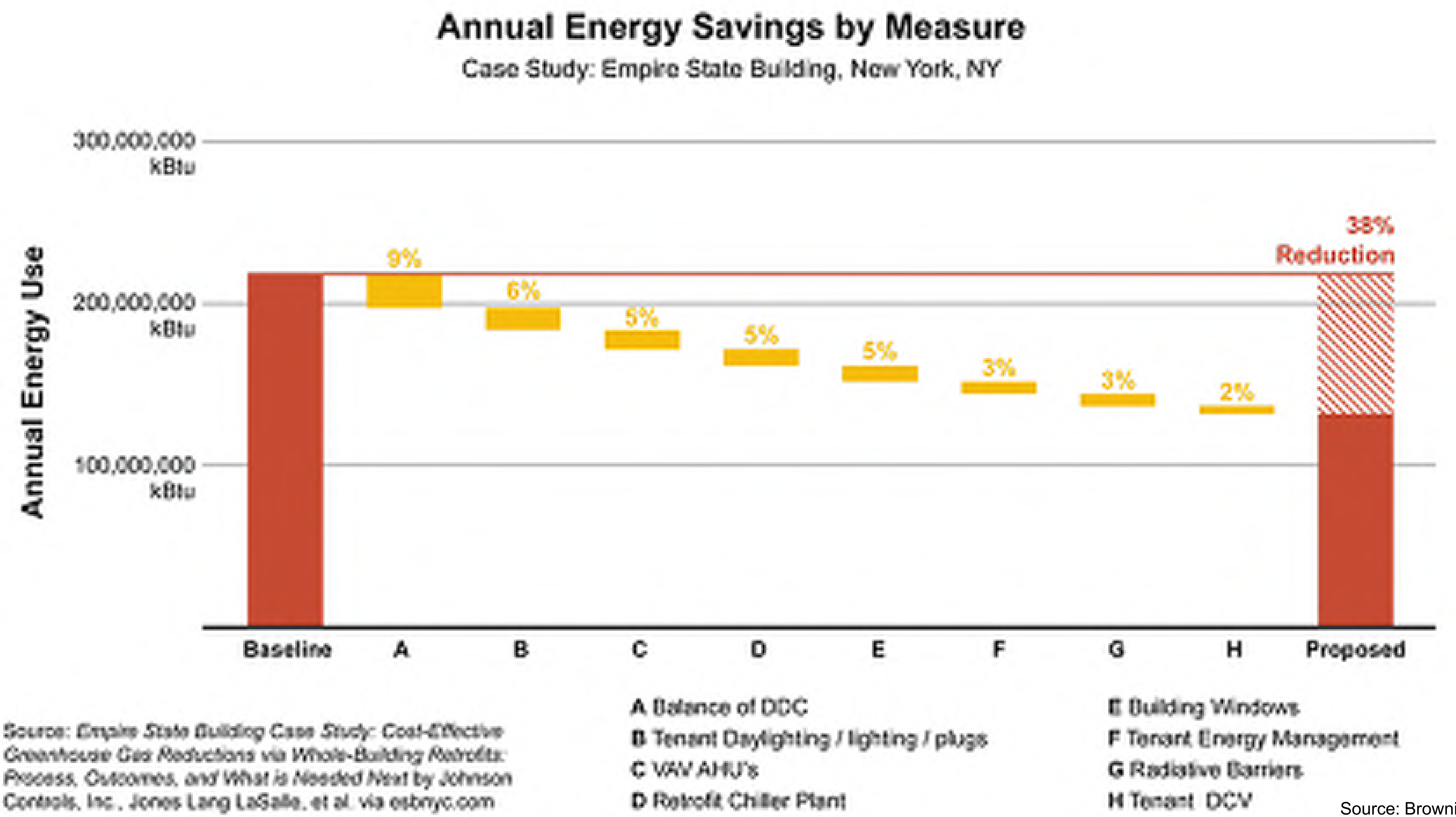
< 150 kgCO2e/m2 = good
> 1,000 kgCO2e/m2 = bad

We now tools and workflows.

Huge opportunity to improve existing buildings.

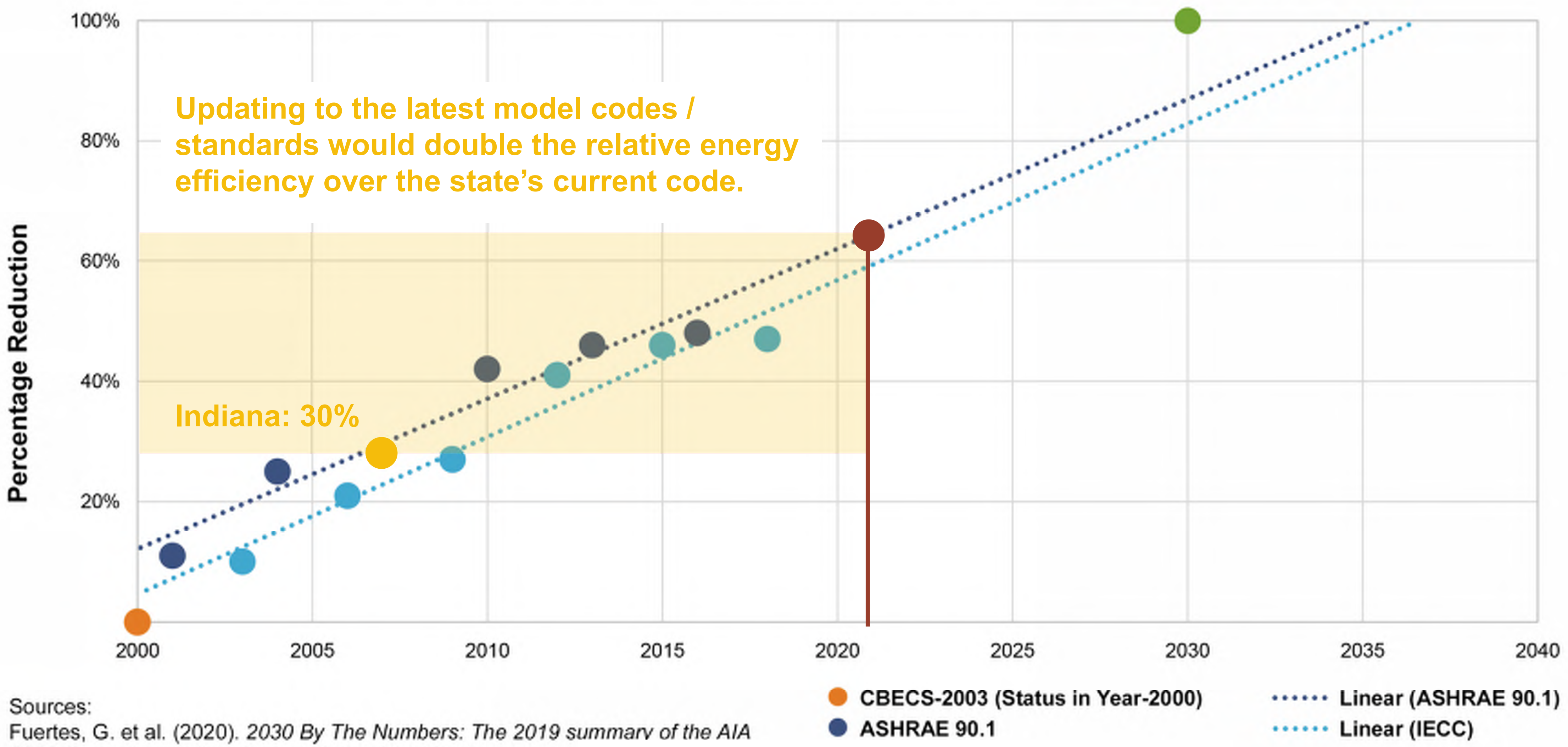


Source: Browning Day



Source: Browning Day

Predicted EUI Reduction in Building Energy Codes (2000-2019)



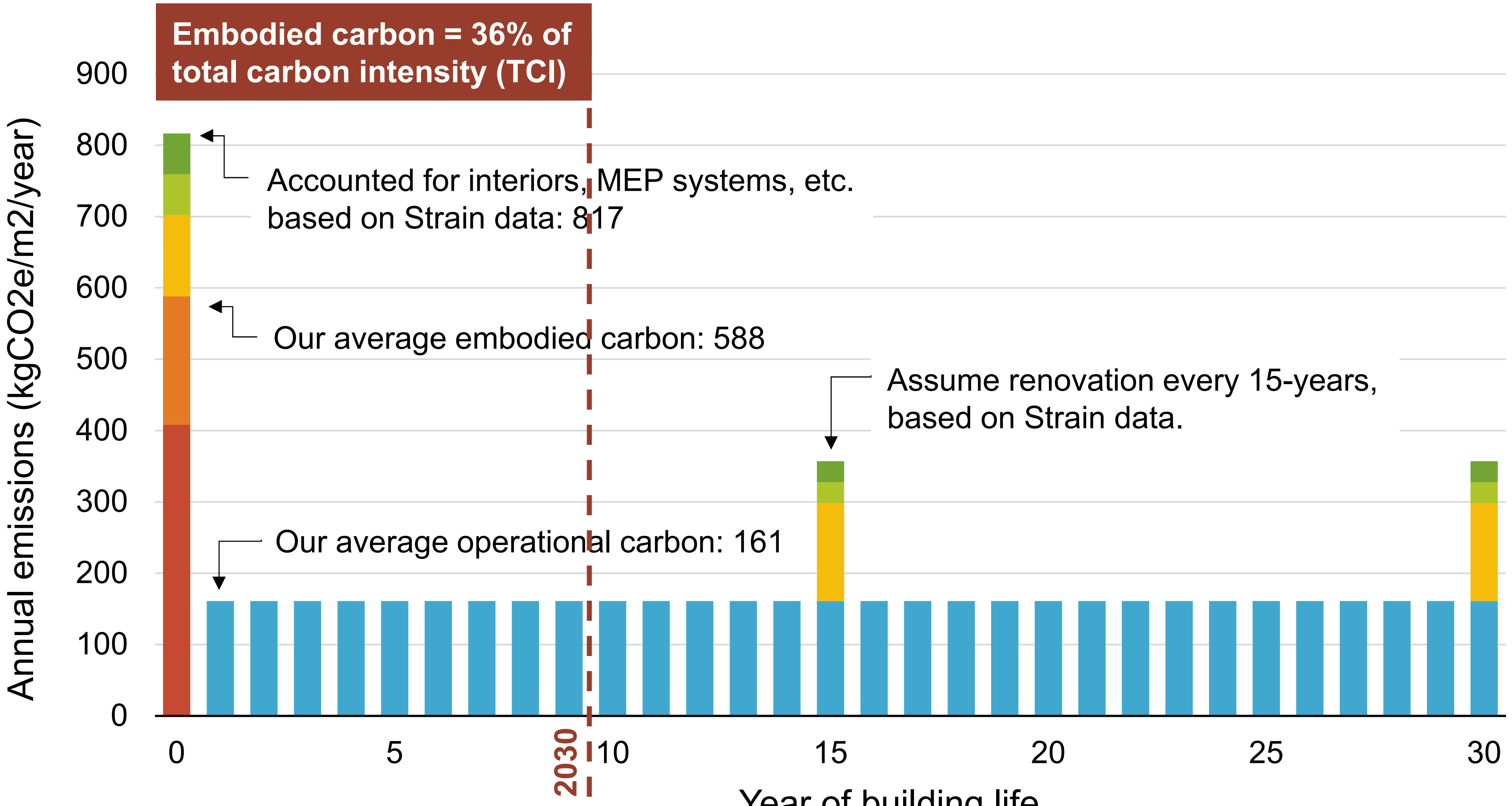
Sources:
Fuertes, G. et al. (2020). *2030 By The Numbers: The 2019 summary of the AIA 2030 Commitment*. American Institute of Architects.
Edelson, J. (2016). *Zero Energy Performance Index (zEPI)*. N

Source: Browning Day

How low can we go?

Embodied and Operational Carbon

For a new building built in 2021

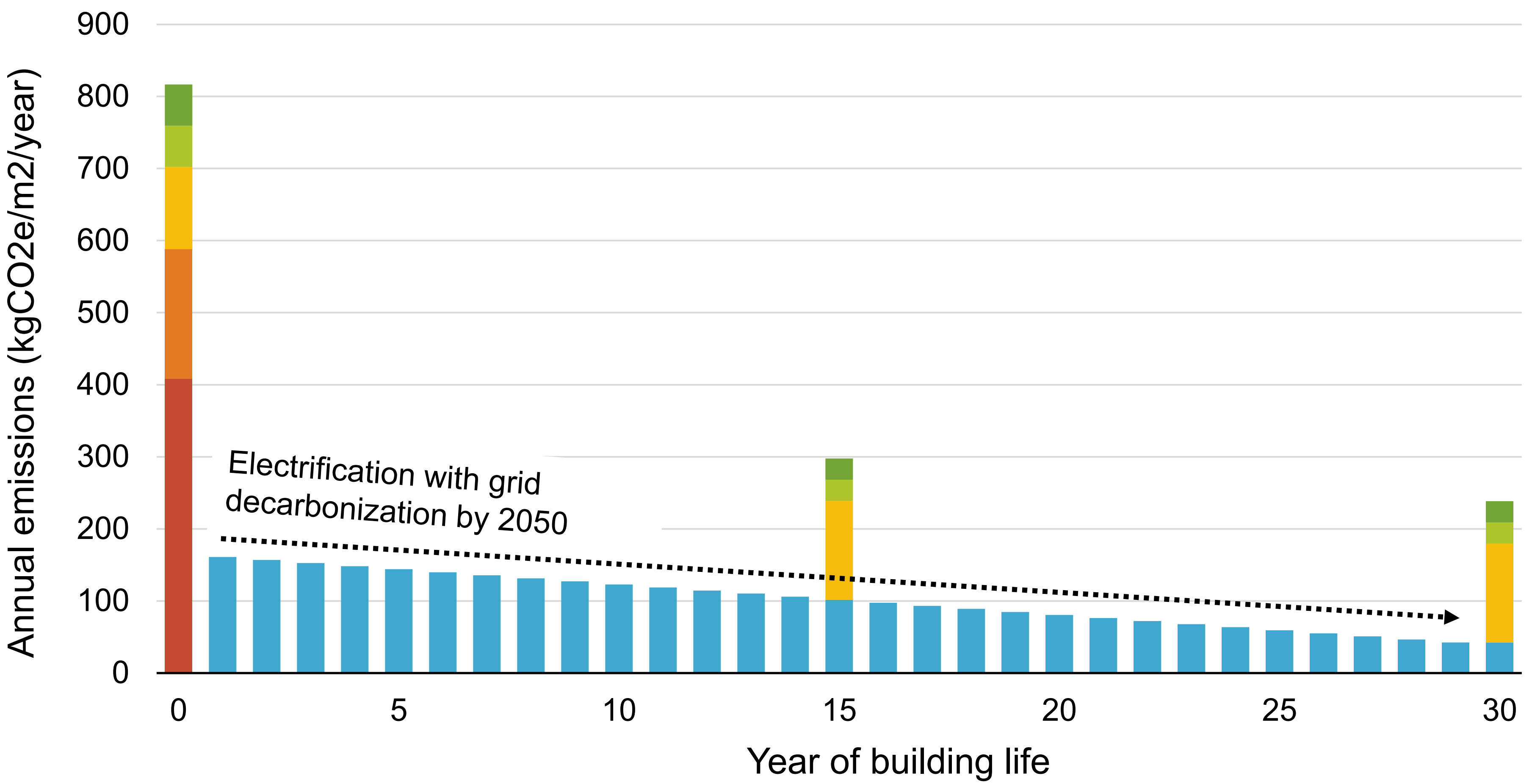


60-Year Lifetime
Total Carbon Intensity

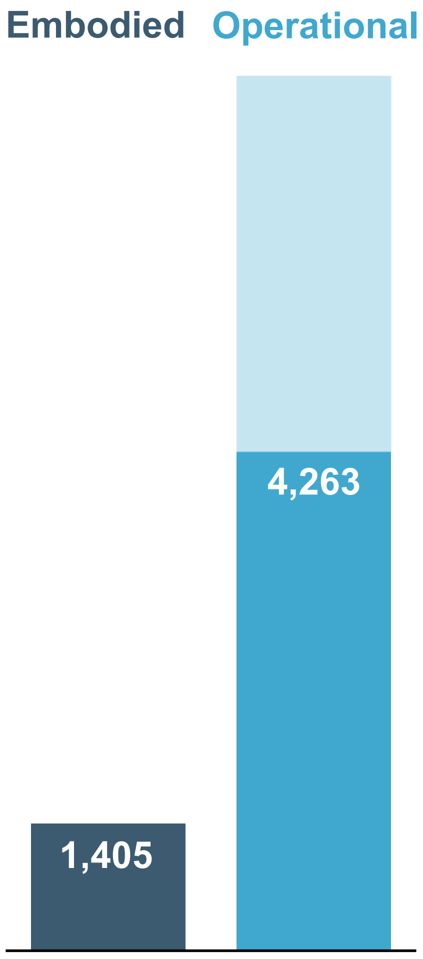
11,065
kgCO2e/m2

Embodied and Operational Carbon

For a new building built in 2021



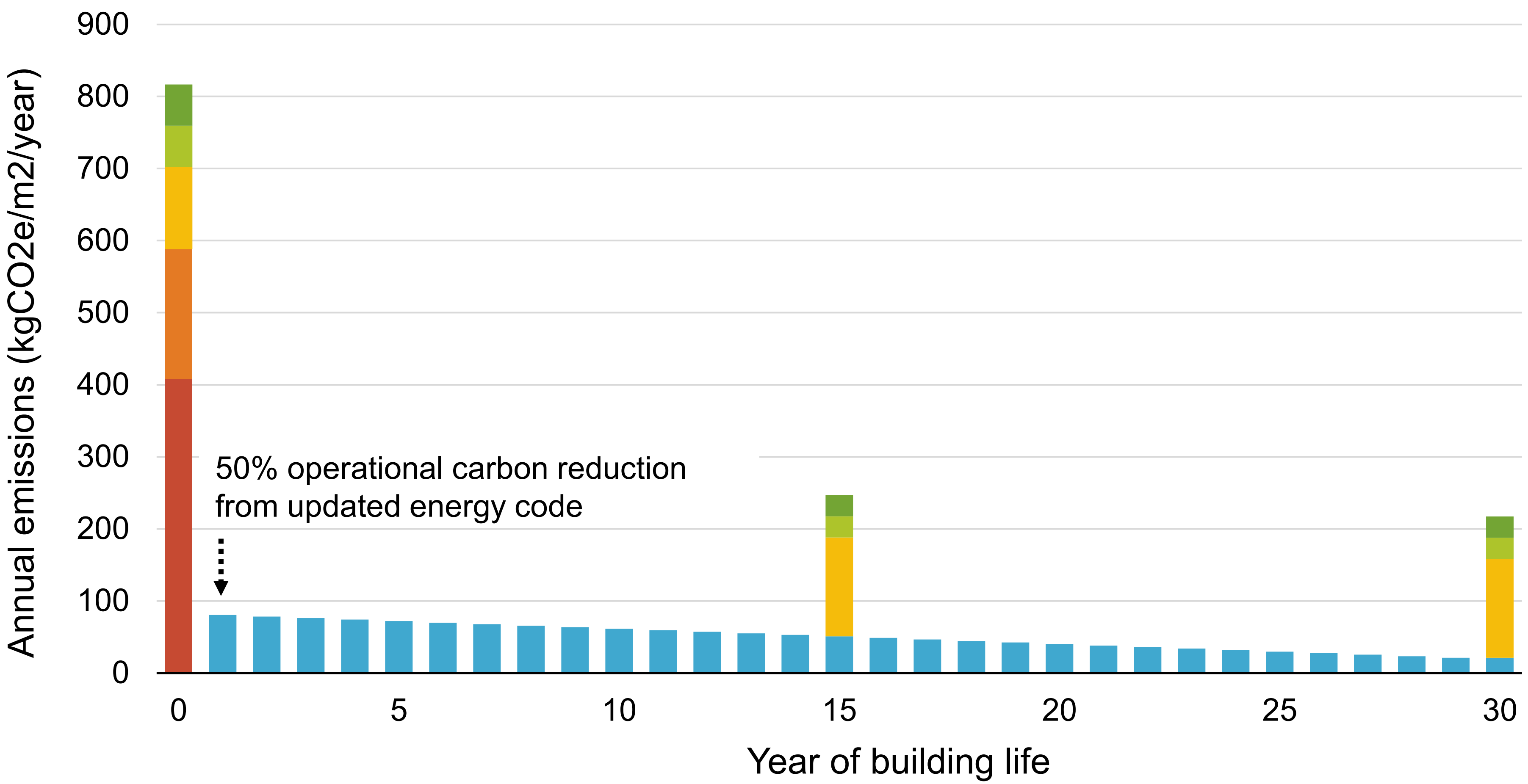
60-Year Lifetime
Total Carbon Intensity



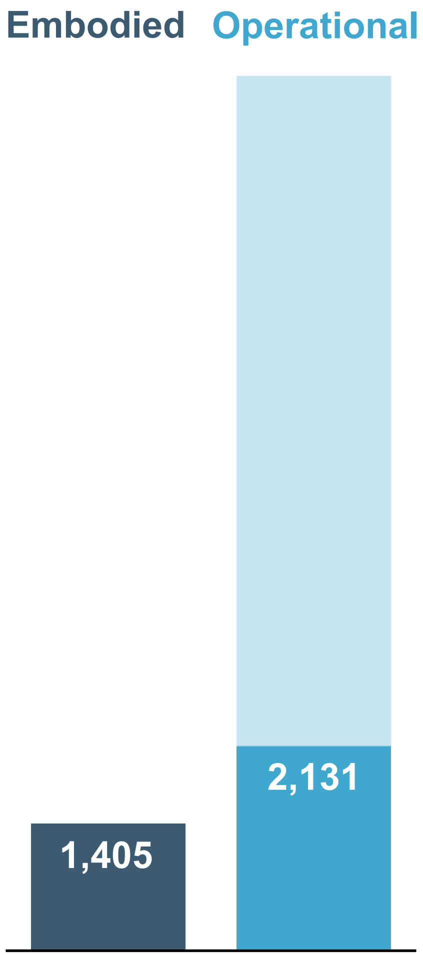
5,668
kgCO2e/m2

Embodied and Operational Carbon

For a new building built in 2021



60-Year Lifetime
Total Carbon Intensity



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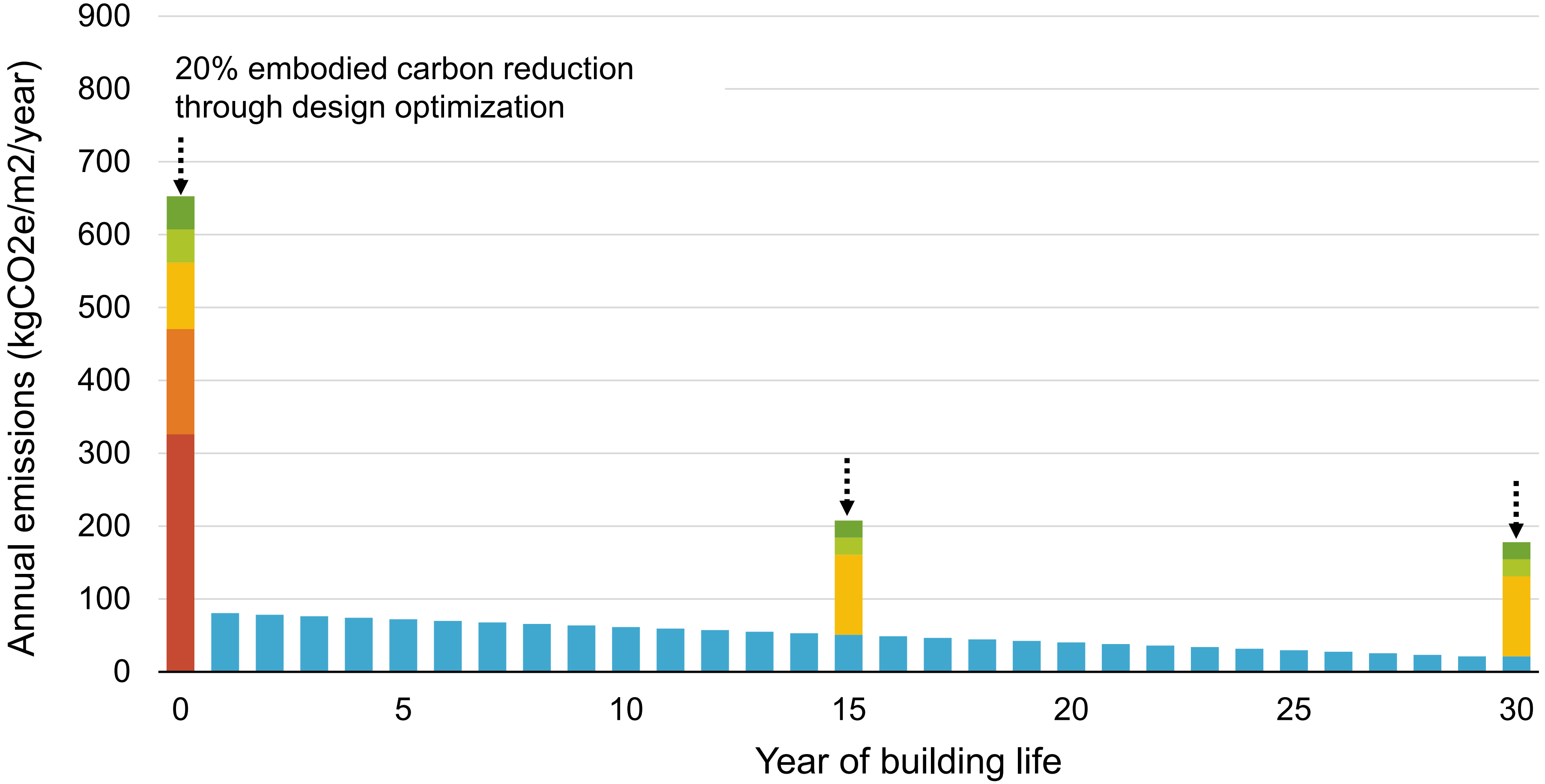
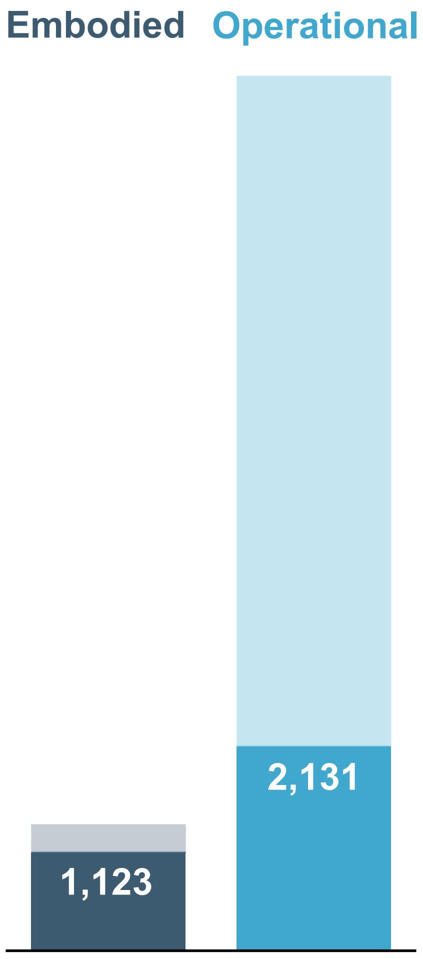
kgCO2e/m2

Embodied and Operational Carbon

For a new building built in 2021



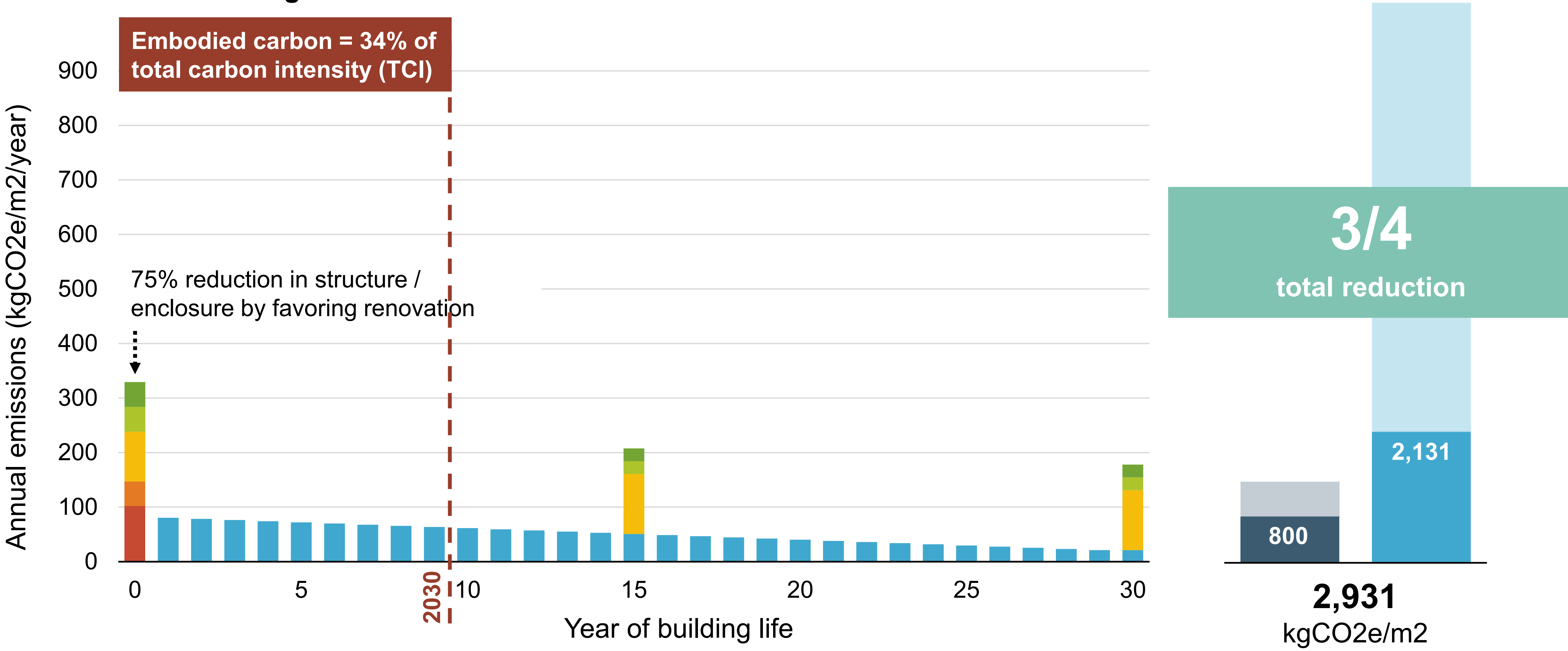
60-Year Lifetime
Total Carbon Intensity



3,255
kgCO2e/m2

Embodied and Operational Carbon

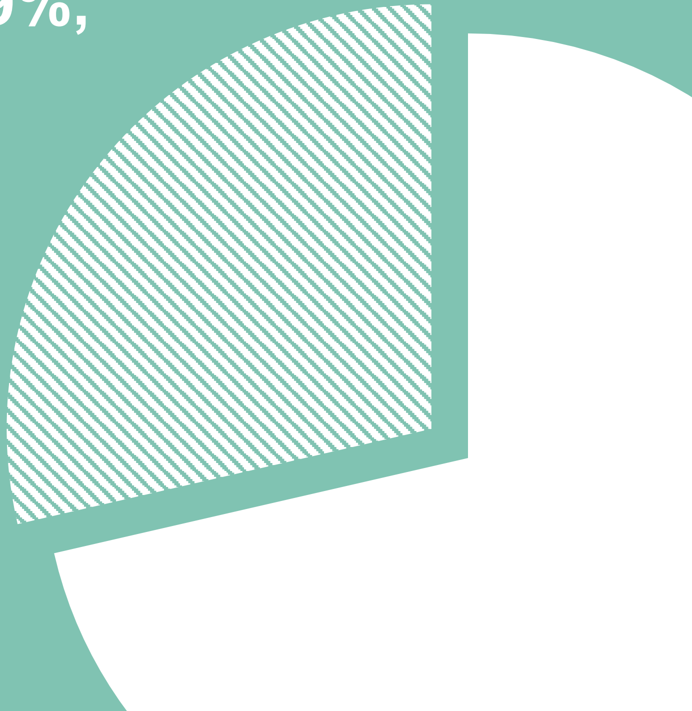
For a new building built in 2021



Four measures can reduce total carbon intensity by 3/4:

1. Electrification with grid decarbonization by 2050.
2. Updated energy code (and strive toward net zero).
3. Design optimization for (≥ 20%) embodied carbon.
4. Prioritize renovation.

These measure could reduce total U.S. emissions by 29%, saving over 1.5 Billion Tonnes of CO2e every year.



How to achieve zero carbon?

Operational carbon:

- Advanced refrigerants.
- On-site renewable energy with smart systems and demand flexibility.
- Utilize battery backups and EVs in an aggregator program.

Embodied:

- Carbon sink materials when possible.

Thank you!

Why Embodied Carbon Matters, and What You Should Do About It

Daniel Overbey, AIA, NCARB, LEED Fellow, WELL AP, EcoDistricts AP

REBUILD 2021

October 7, 2021