

EMBODIED CARBON IN BUILDINGS



EMBODIED CARBON IN BUILDINGS

Session 2: Materials and Carbon



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Coauthor with her boss, Richard Stein:

Energy Required for Building Construction

(Chapter in a book, *Energy Conservation Through Building Design*, edited by Don Watson.)

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FEATURE ARTICLE

Embodied Energy--Just What Is It and Why Do We Care?

Almost all the attention paid to energy conservation in buildings has focused on reducing their operating energy, but embodied energy can add up to many years' worth of operating energy in an efficient building.

by [Nadav Malin](#)

Comparing Embodied Energy with Operating Energy

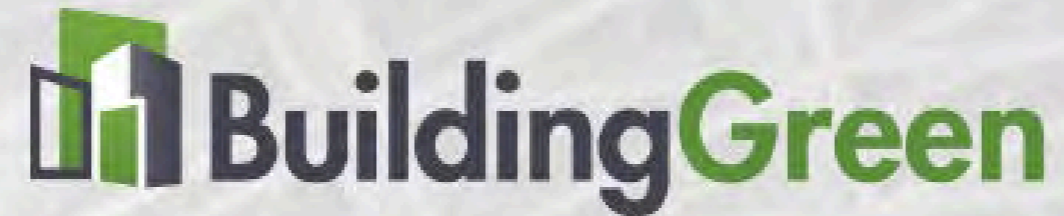
Estimates provided by Professor Ray Cole of the University of British Columbia's School of Architecture. House modeled is a 3,750 ft² ranch. Energy-efficient version assumes ceiling R-values raised from R-24 to R-42, 2x4 walls replaced with 2x6 walls, additional glazing on south elevation, and added thermal mass to temper indoor temperatures.

Almost all the attention paid to energy conservation in buildings has focused on reducing their operating energy. Given the energy hogs that many buildings were (and are), this focus is appropriate. As builders and architects succeed in making their buildings more efficient, however, the energy used to *build* buildings starts to look significant. This *embodied energy* can add up to many years' worth of

Comparing Embodied Energy with Operating Energy

	Heating Energy MMBtu/year (GJ/year)	Embodied Energy MMBtu (GJ)	Embodied Energy Expressed as years of heating energy
Conventional house, Vancouver	101 (107)	948 (1,000)	9.4
Conventional house, Toronto	136 (143)	948 (1,000)	7.0
Energy-efficient version, Vancouver	57 (60)	1,019 (1,075)	17.9
Energy-efficient version, Toronto	78 (82)	1,019 (1,075)	13.1

Estimates provided by Professor Ray Cole of the University of British Columbia's School of Architecture. House modeled is a 3,750 ft² ranch. Energy-efficient version assumes ceiling R-values raised from R-24 to R-42, 2x4 walls replaced with 2x6 walls, additional glazing on south elevation, and added thermal mass to temper indoor temperatures.



SPOTLIGHT REPORT

The Urgency of Embodied
Carbon and What You
Can Do About It

EMBODIED CARBON IN BUILDINGS





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Lowering the embodied carbon of concrete

Jeremy Gregory

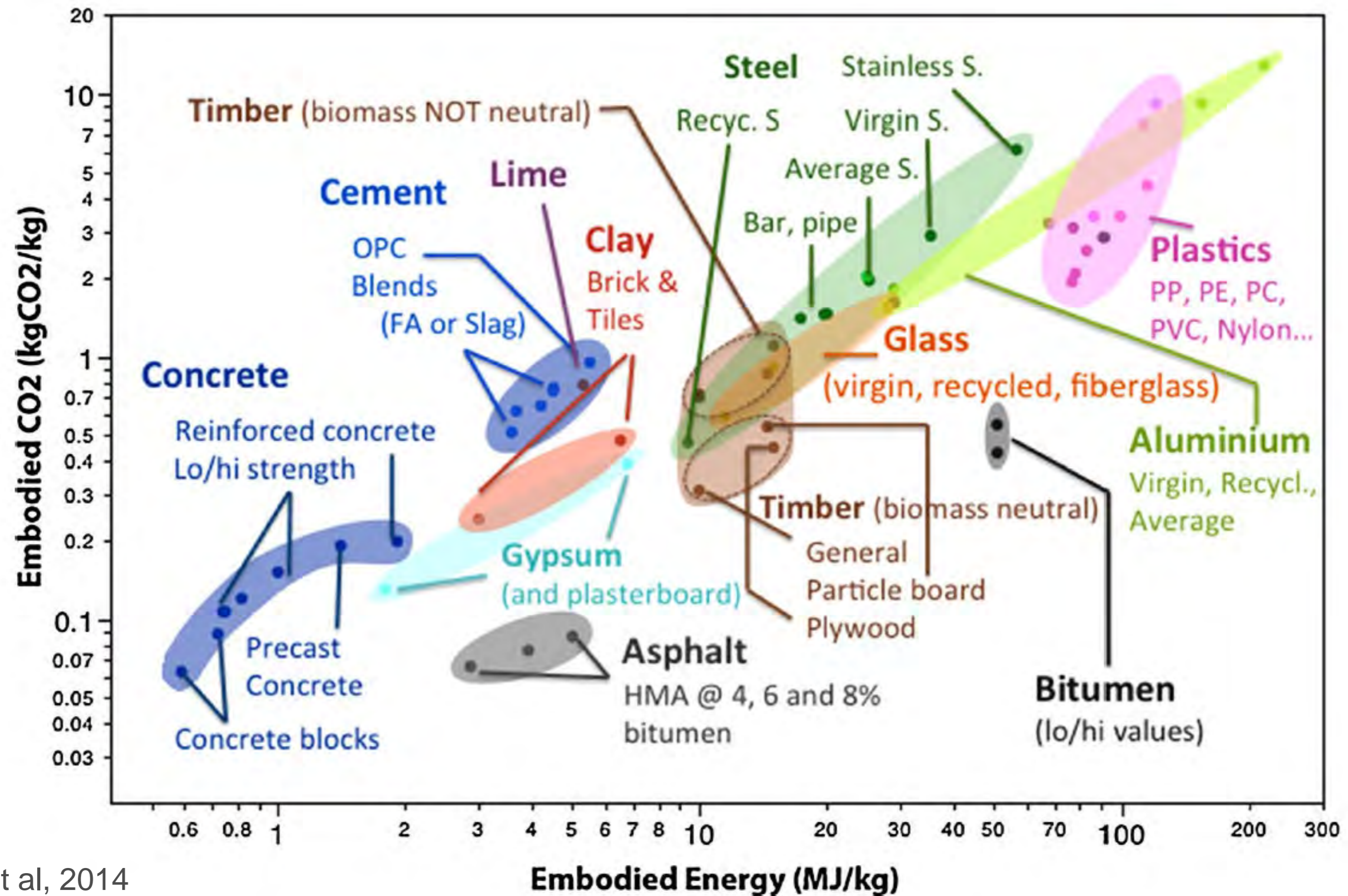
Executive Director, MIT Concrete Sustainability Hub

Embodied Carbon Conference

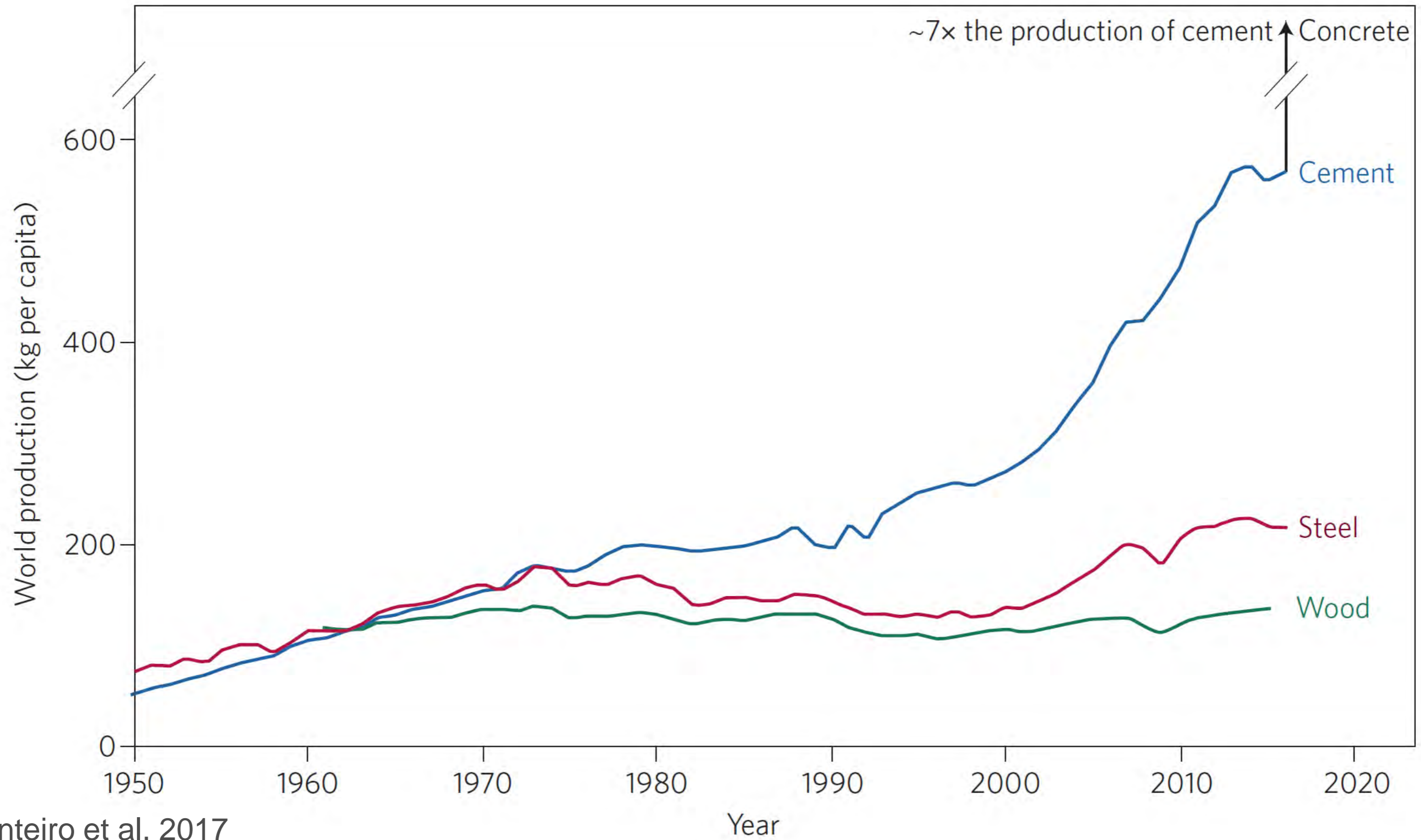
MIT

May 31, 2019

Concrete is a low-impact material



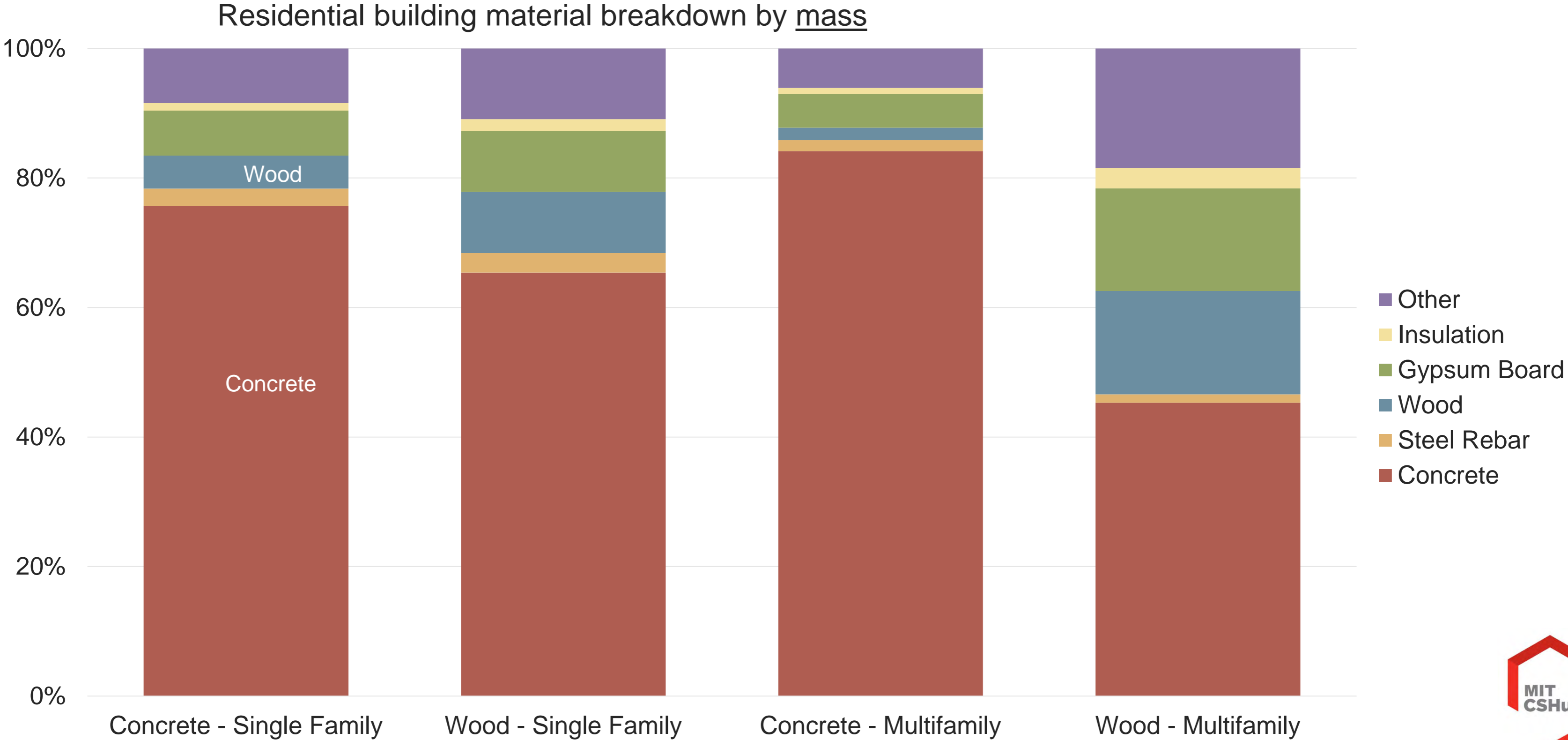
Concrete is the most used building material in the world



Source: Monteiro et al, 2017



Concrete is a significant portion of nearly all buildings

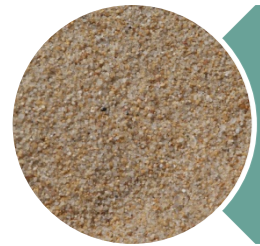


Concrete is a mixture that can be designed to meet performance requirements

Concrete Constituents



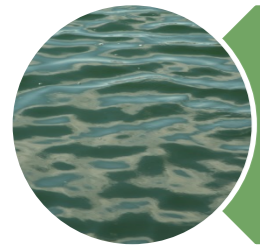
Coarse aggregates



Fine aggregates



Binder



Water



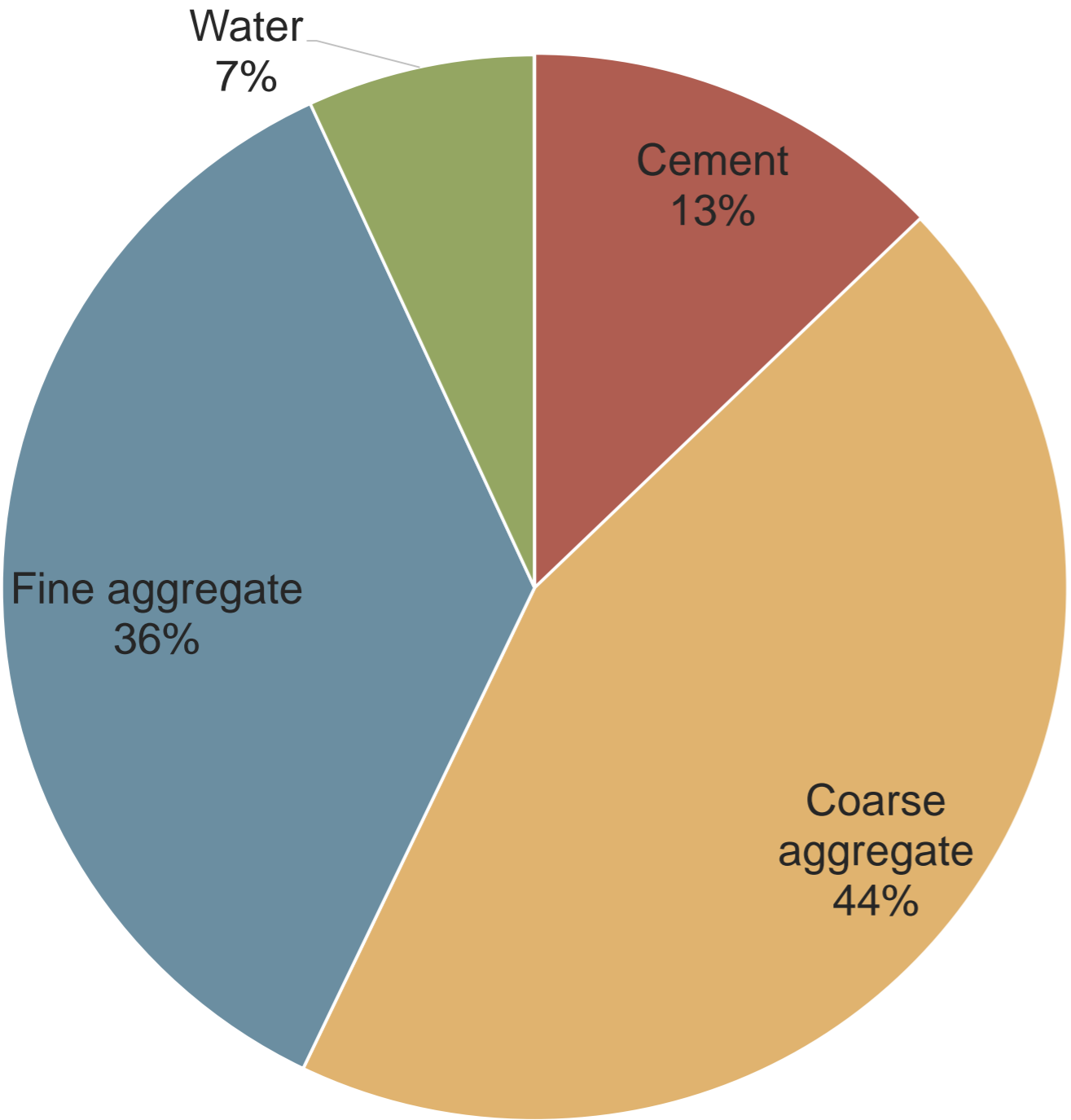
Admixtures

Performance Requirements

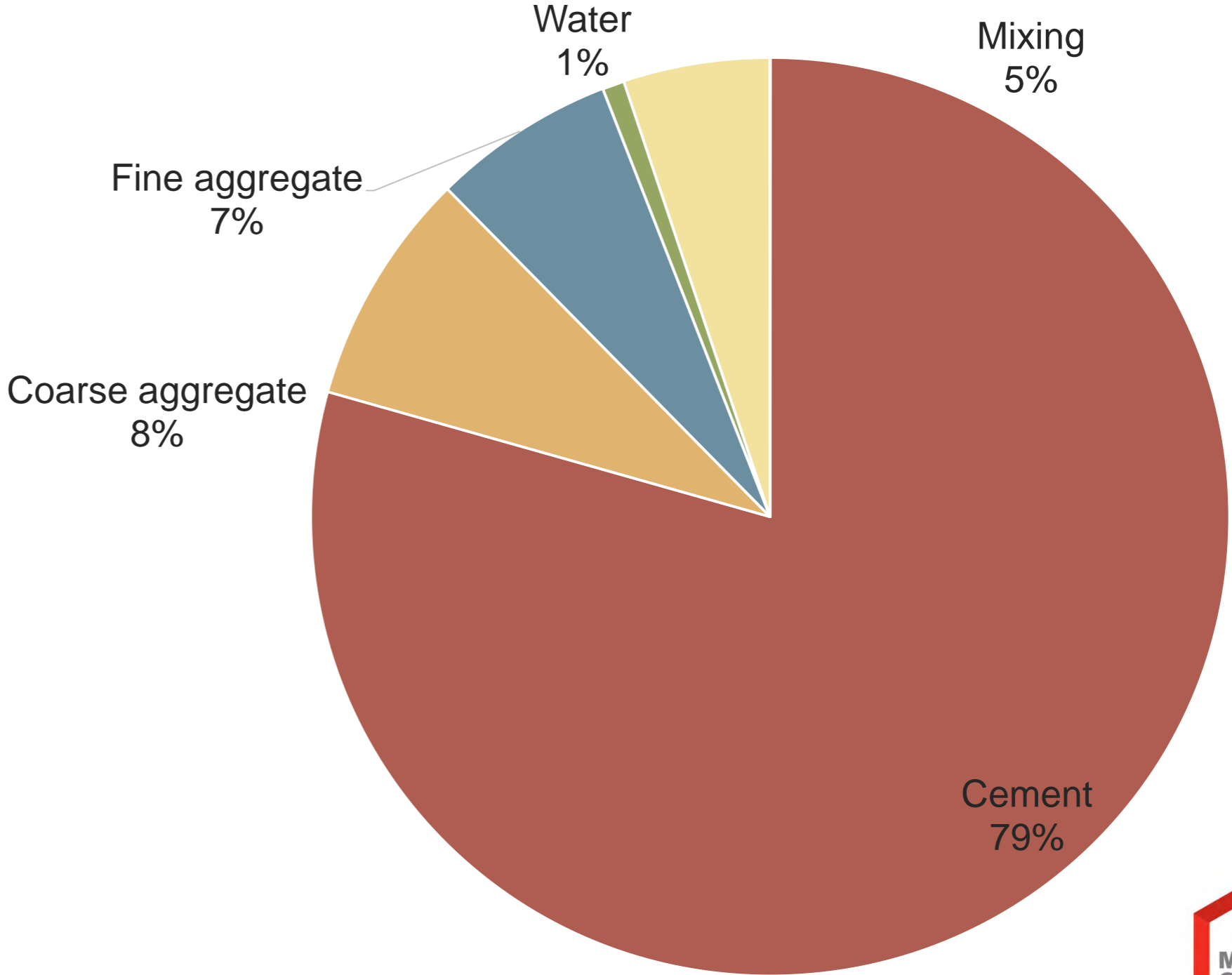
- 28-Day strength
- 3-Day strength
- Modulus of elasticity
- Density
- Slump
- Thermal control
- Chloride permeability
- Alkali-silica reaction
- Freeze-thaw
- Other durability

Cement drives concrete's environmental impact

Constituent contribution by **mass**



Constituent contribution by **GHG emissions**



3000 psi mixture with no SCMs



There are numerous solutions available today for lowering concrete's environmental impact



Cement

- **Alternative fuels**
- **Energy efficiency**
- **Clinker replacement**
- Cement formulation
- Carbon sequestration at cement plant
- Carbon sequestration in cement production





Concrete

- **Cement replacement**
- Carbon sequestration in concrete production
- Carbon sequestration in aggregate production

Bold = widespread use today

Firms are reporting concrete environmental footprint through environmental product declarations

LEED is driver of EPDs

Summary of Environmental Product Declaration		Environmental Impacts 			
Central Concrete		Impact name	Unit	Impact per m3	Impact per cyd
Mix	340PG9Q1	Total primary energy consumption	MJ	2,491	1,906
San Jose Service Area		Concrete water use (batch)	m3	6.66E-2	5.10E-2
EF V2 Gen Use P4000 3" Line 50% SCM		Concrete water use (wash)	m3	8.56E-3	6.55E-3
Performance Metrics 		Global warming potential	kg CO2-eq	271	207
		Ozone depletion	kg CFC-11-eq	5.40E-6	4.14E-6
		Acidification	kg SO2-eq	2.26	1.73
		Eutrophication	kg N-eq	1.31E-1	1.00E-1
		Photochemical ozone creation	kg O3-eq	46.6	35.7
28-day compressive strength	4,000 psi				
Slump	4.0 in				

A sample EPD for a concrete mix design by Central Concrete Supply Co.

Credit: Central Concrete Supply



Concrete EPDs are not set up for comparison

Mix Code	Plant	Perf.	Impacts							
		CS	TPE	CWB	CWW	GWP	ODP	AP	EP	POCP
	<i>minimum</i>	2,000	2.155E+03	6.871E-02	4.504E-03	2.058E+02	3.634E-06	1.513E+00	8.143E-02	2.568E+01
	<i>maximum</i>	6,000	3.629E+03	7.287E-02	4.504E-03	4.819E+02	6.637E-06	3.466E+00	1.395E-01	4.745E+01
325PC901	Brentwood	2,500	2.556E+03	6.871E-02	4.504E-03	3.058E+02	4.237E-06	2.174E+00	9.251E-02	3.072E+01
325PC902	Brentwood	2,500	2.552E+03	7.287E-02	4.504E-03	3.056E+02	4.249E-06	2.173E+00	9.197E-02	3.067E+01
325PC9D1	Brentwood	2,500	2.231E+03	6.871E-02	4.504E-03	2.529E+02	3.634E-06	1.784E+00	8.243E-02	2.572E+01
325PC9D2	Brentwood	2,500	2.225E+03	7.287E-02	4.504E-03	2.525E+02	3.638E-06	1.784E+00	8.143E-02	2.568E+01
325PC9Q1	Brentwood	2,500	2.161E+03	6.871E-02	4.504E-03	2.062E+02	4.591E-06	1.515E+00	1.004E-01	2.760E+01
325PC9Q2	Brentwood	2,500	2.155E+03	7.287E-02	4.504E-03	2.058E+02	4.571E-06	1.513E+00	9.997E-02	2.754E+01
325PG9C1	Brentwood	2,500	2.536E+03	6.871E-02	4.504E-03	3.047E+02	4.147E-06	2.170E+00	8.987E-02	3.063E+01
325PG9D1	Brentwood	2,500	2.311E+03	6.871E-02	4.504E-03	2.674E+02	3.760E-06	1.894E+00	8.401E-02	2.707E+01
325PG9Q1	Brentwood	2,500	2.344E+03	6.871E-02	4.504E-03	2.310E+02	5.036E-06	1.704E+00	1.109E-01	3.082E+01
325PG9Q2	Brentwood	2,500	2.345E+03	7.287E-02	4.504E-03	2.316E+02	5.064E-06	1.707E+00	1.106E-01	3.085E+01

Impacts vary by 1.5X

These mixes all have different performance requirements
How to establish thresholds?



Prescriptive specifications limit opportunities to reduce concrete environmental impact

Common prescriptive requirements	Occurrence in Specifications
Restriction on SCM quantity	85%
Maximum water-cement ratio	73%
Minimum cementitious content for floors	46%
Restriction on SCM type, characteristics	27%
Restriction on aggregate grading	25%

Performance-based specifications are the best way to spur innovation in low-impact concrete

Design multiple concrete mixtures that meet performance specifications

Mixture	Cost	Env. Impact
A	Low	High
B	Moderate	Moderate
C	High	Low

Transitioning to performance-based specifications requires collaboration to share planning and risk among:

- Architects
- Engineers
- Specifiers
- Constructors
- Developers
- Customers

This can be implemented today if we are willing to change paradigms

Two approaches to standardizing reduction of concrete environmental impacts

Threshold

- Used in CA Buy Clean Act
- Need industry average and individual company EPDs
- *How to strive for comparability (define performance?)?*
- *How to set thresholds?*
- *Concrete vs cement?*
 - Cement categorization is simpler (Type I, II, etc.)
 - Concrete categorization is about more than strength

Performance-based specifications

- Eliminate prescriptive requirements (e.g., min cm, max w/cm, limits on SCMs, cement type)
- Enable innovation in mixture design
- *How is mixture selected considering trade-offs of performance, env impact, and cost?*
- *What are challenges associated with adoption of PBS?*





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Thank you

jgregory@mit.edu

<http://cshub.mit.edu/>

EMBODIED CARBON IN BUILDINGS

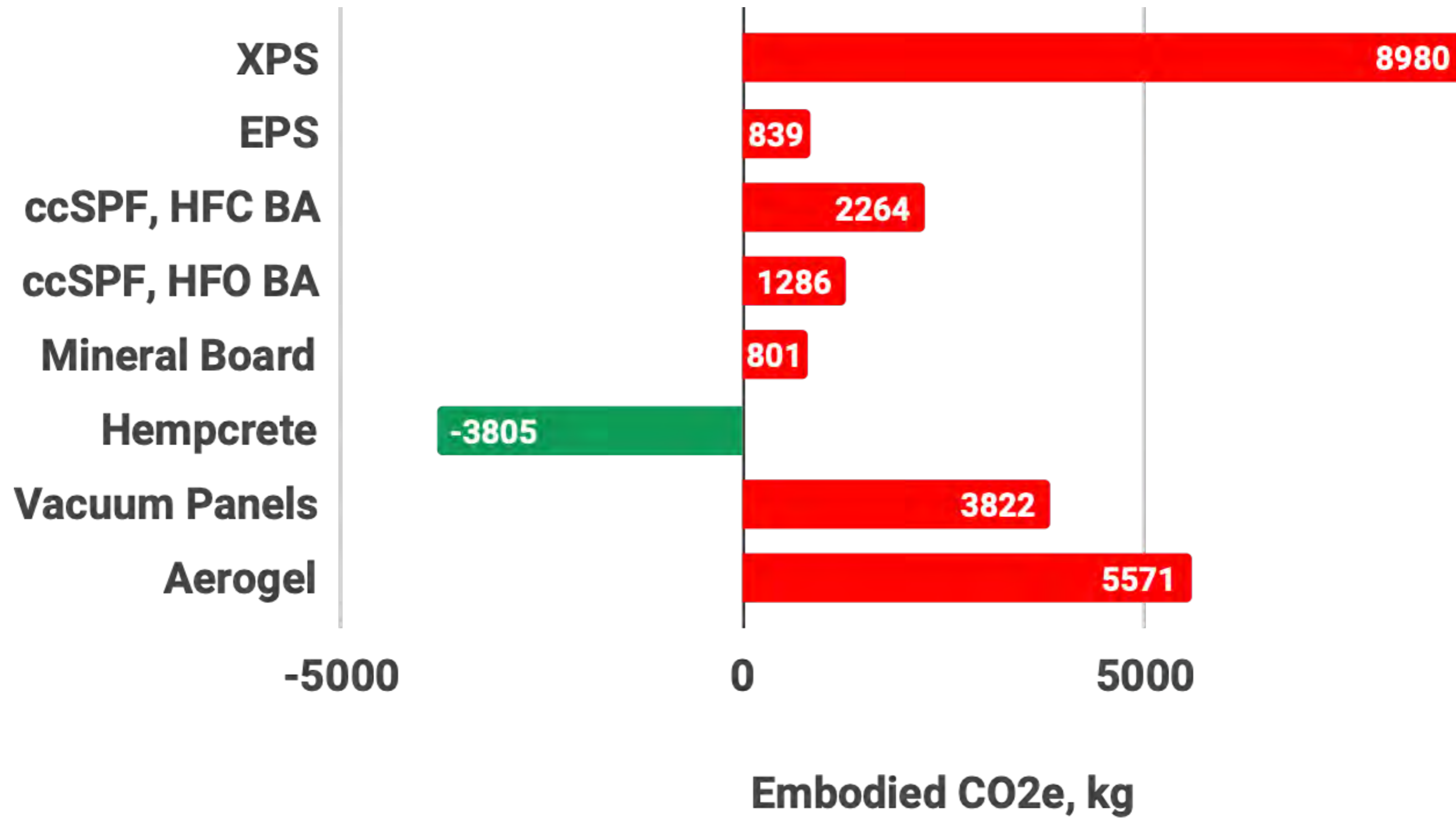




Source: ModCell

Renewable Materials

Embodied Carbon in Materials, Boston, MA ~ May 31, 2019



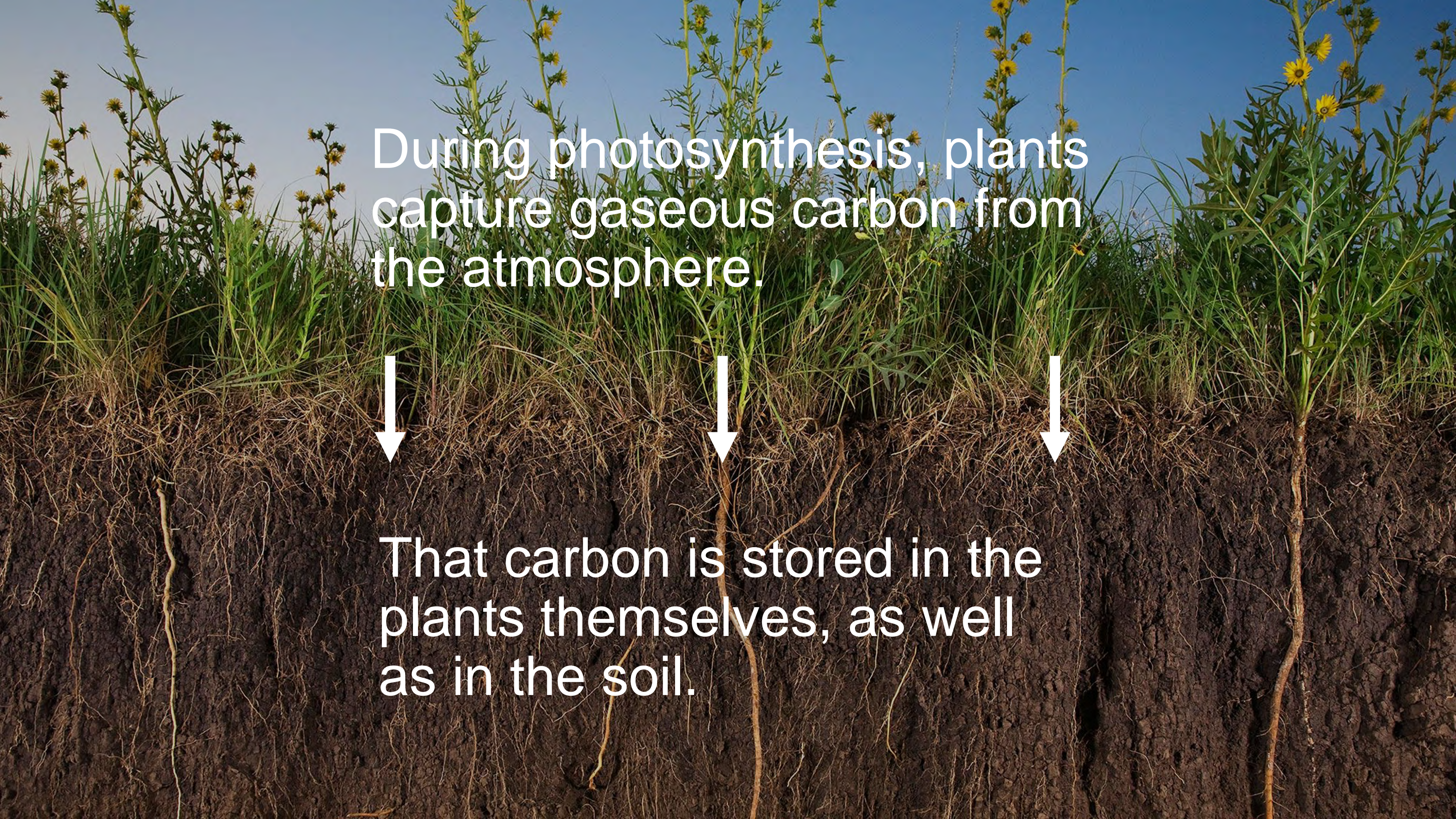
**Embodied CO2e of Foundation Wall Insulation
R-20, 233 m2**

Wait! What's this? A negative number?



Yes, a material that stores more atmospheric carbon than was emitted in harvesting & manufacturing! This opens up a whole new paradigm — materials with carbon capture and storage potential!

How does this work?



During photosynthesis, plants capture gaseous carbon from the atmosphere.

That carbon is stored in the plants themselves, as well as in the soil.

There are lots of plant-based, carbon-storing building materials



Timber



Wood Fiber Board



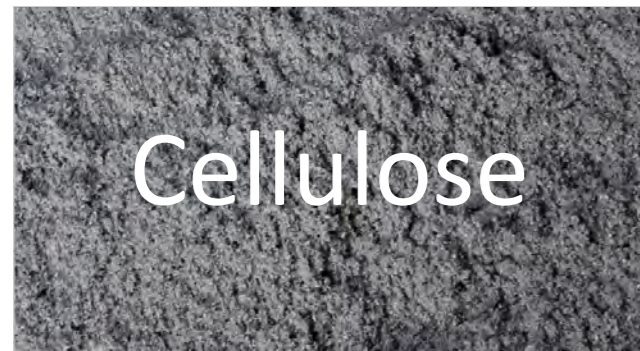
Cork



ReWall



Waste Textiles



Cellulose



Straw



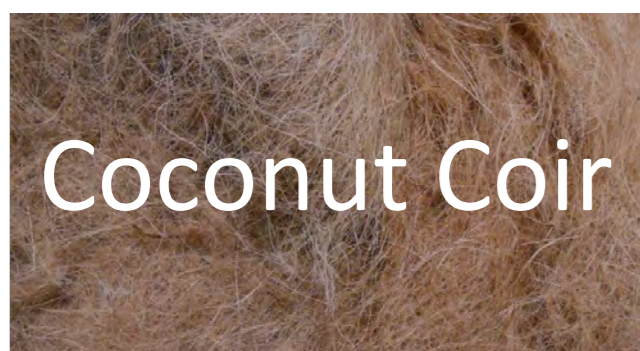
Mycelium



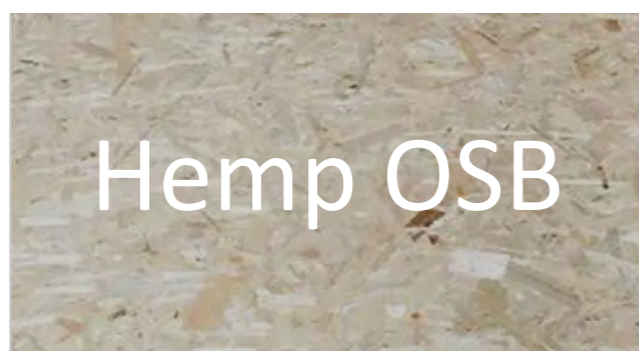
Rice Hulls



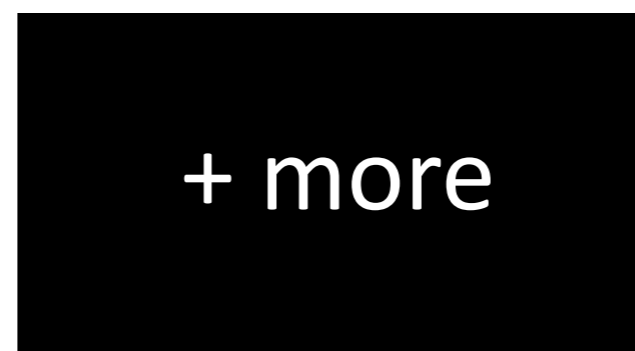
Bamboo /
BamCore



Coconut Coir



Hemp OSB



+ more

And few or **no red list** chemicals!

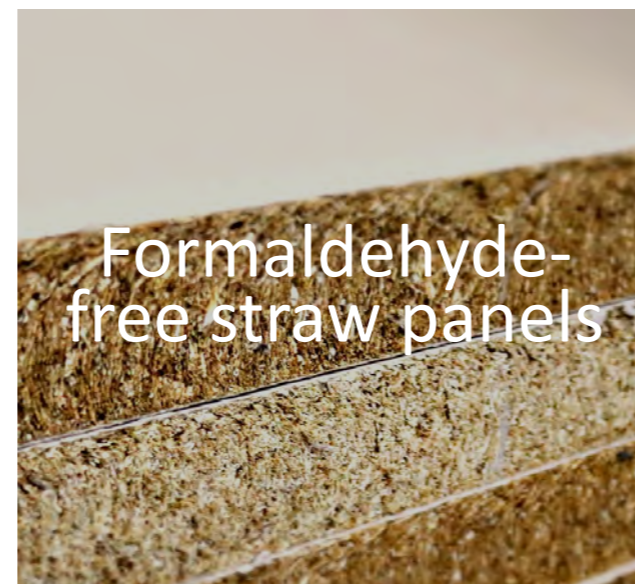
...some that are mineral-based



...and some interesting hybrids.



2.16 billion tons of grain straw were grown globally in 2016. That's enough carbon storage to offset all current transportation GHG emissions and more than replace all current insulation materials.



EMBODIED CARBON IN BUILDINGS





Building Materials and Construction Emissions

Lindsay Rasmussen, CPHC[®], Assoc. AIA, LEED Green Associate
Program Manager | Architecture 2030



By 2060, world population is expected to increase by about

2.67 billion people

Source: World Bank



By 2060, world *urban population* is expected to increase by about

2.75 billion people

absorbing the entire population growth estimate.

Source: UN Population Division



Today, global building floor area is about

223 billion m²

Source: Global Status Report, GABC



By 2060, global building floor area will increase by

230 billion m²

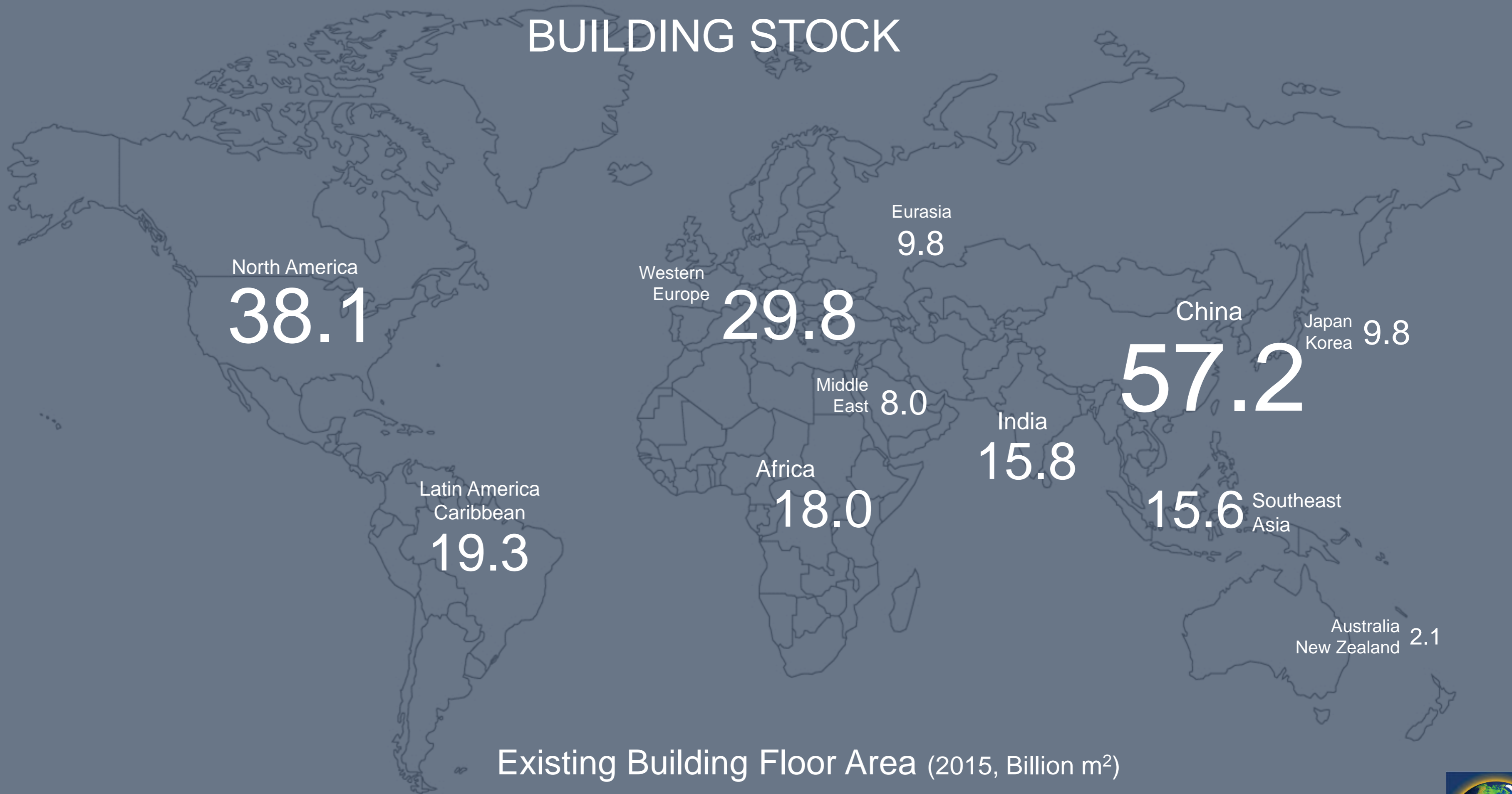
or *double* the current worldwide building stock.

Source: Global Status Report, GABC





BUILDING STOCK

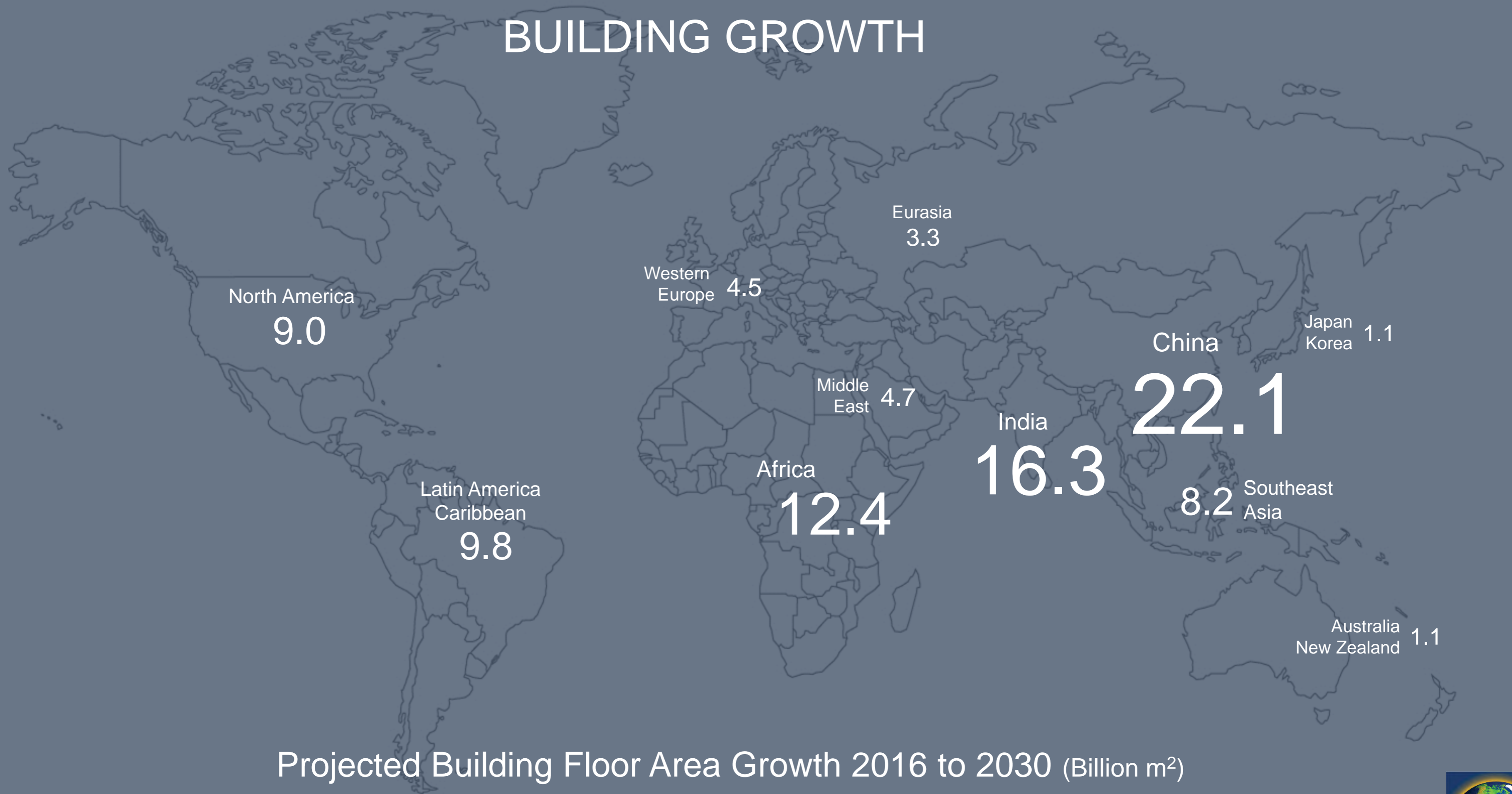


Existing Building Floor Area (2015, Billion m²)

Source: Architecture 2030 Global ABC, Global Status Report 2016



BUILDING GROWTH

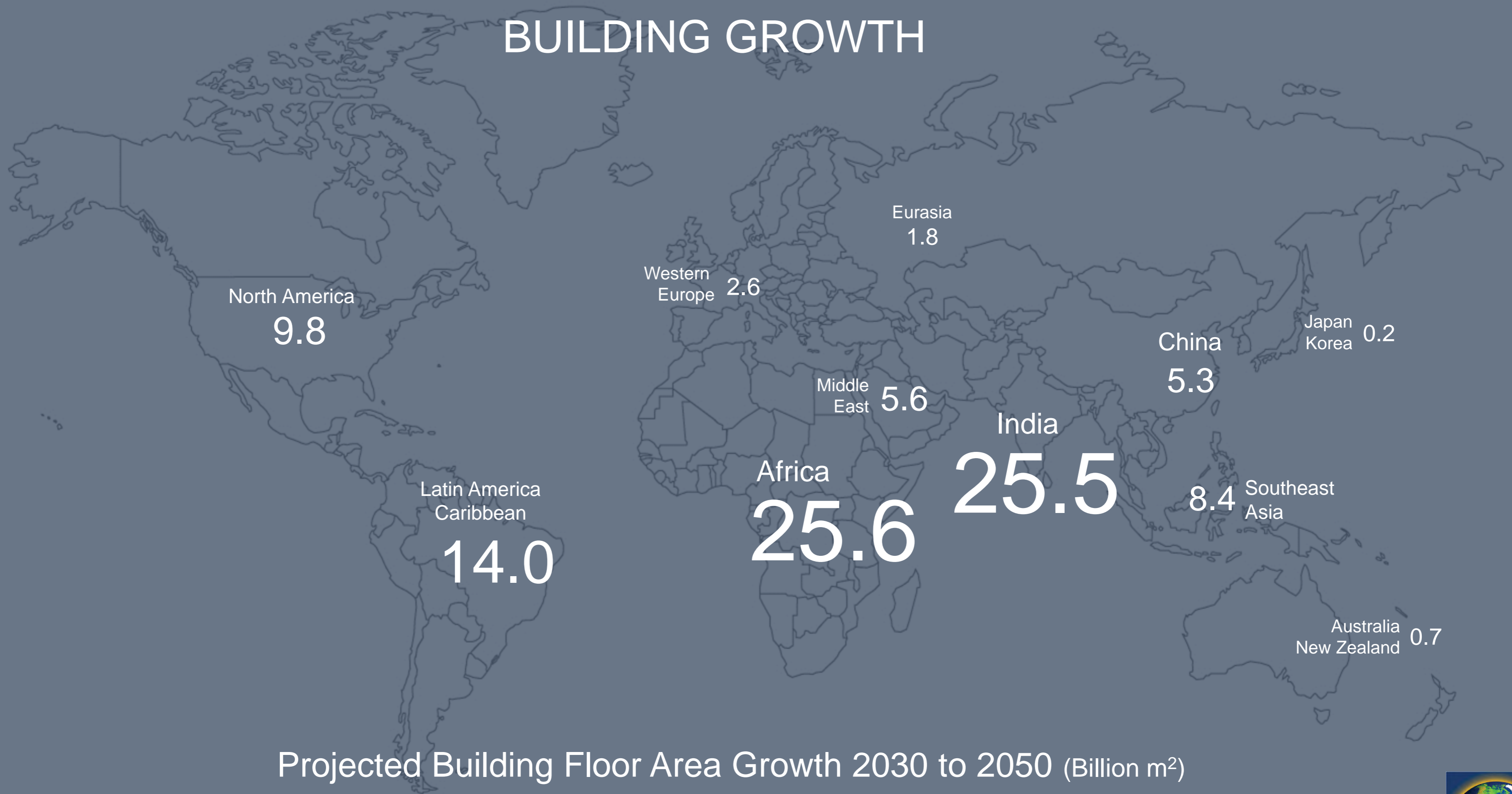


Projected Building Floor Area Growth 2016 to 2030 (Billion m²)

Source: Global ABC, Global Status Report 2016



BUILDING GROWTH

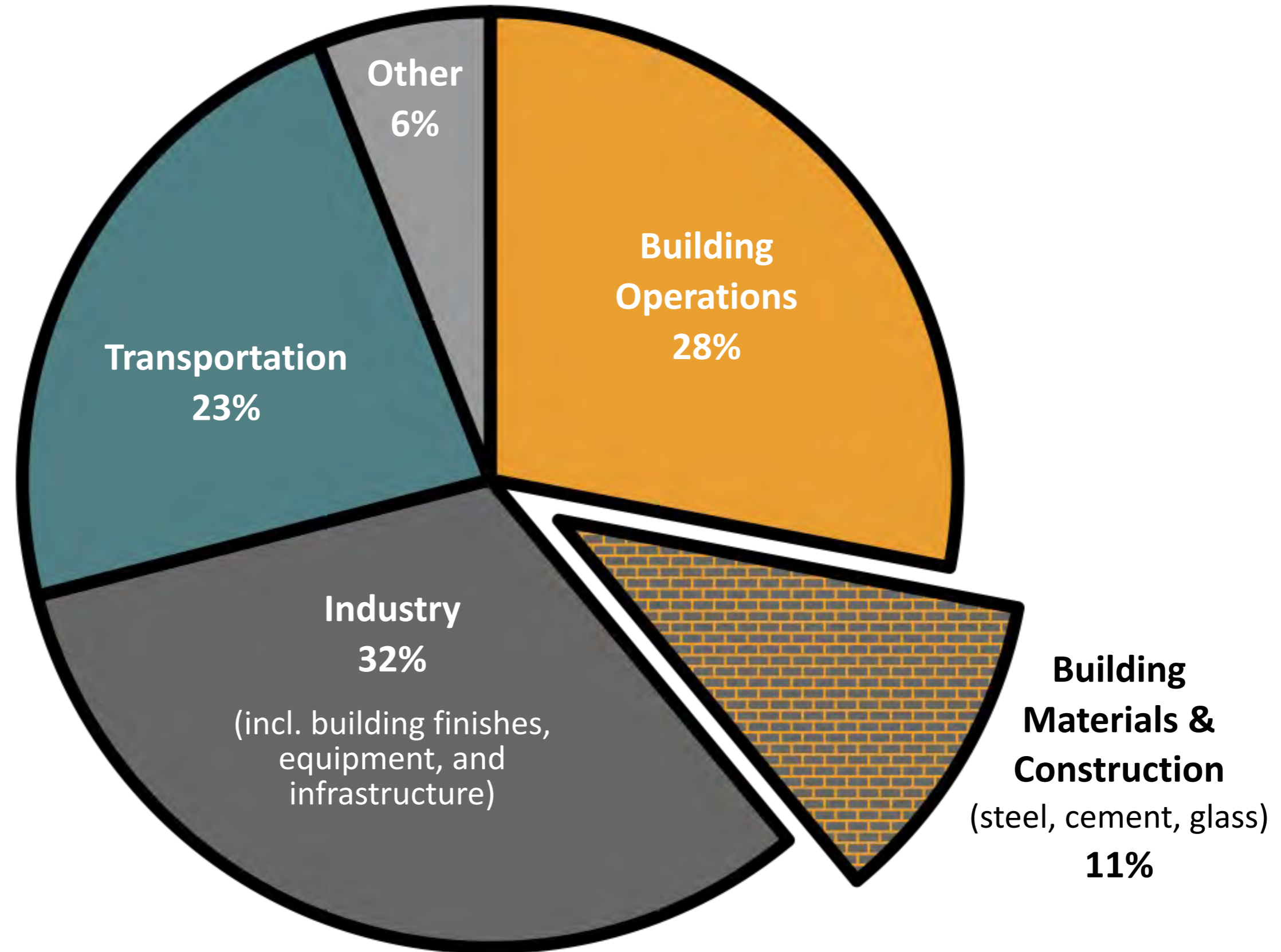


Projected Building Floor Area Growth 2030 to 2050 (Billion m²)

Source: Global ABC, Global Status Report 2016



Global CO₂ Emissions by Sector

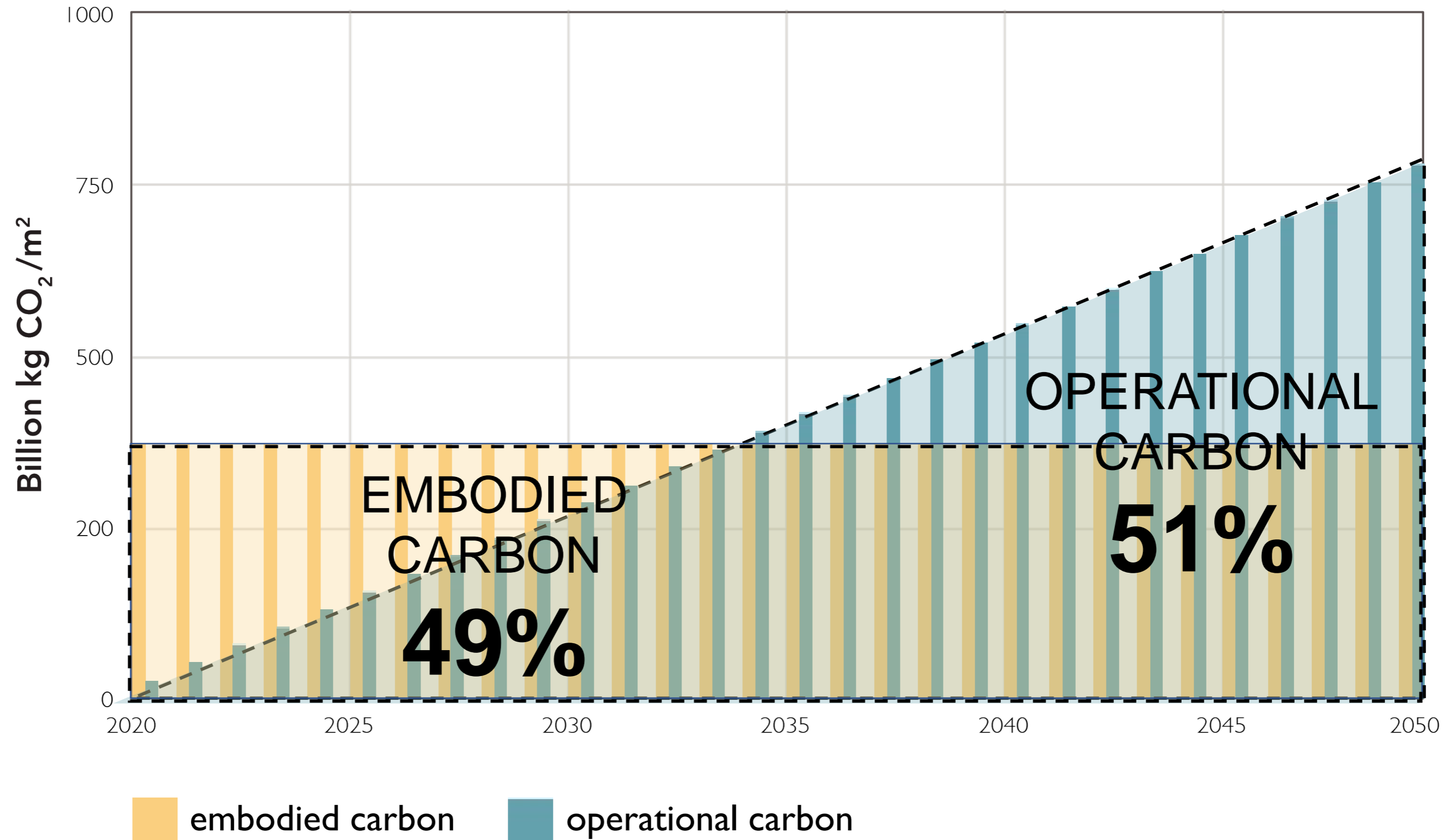


Source:
2018 Global ABC Report

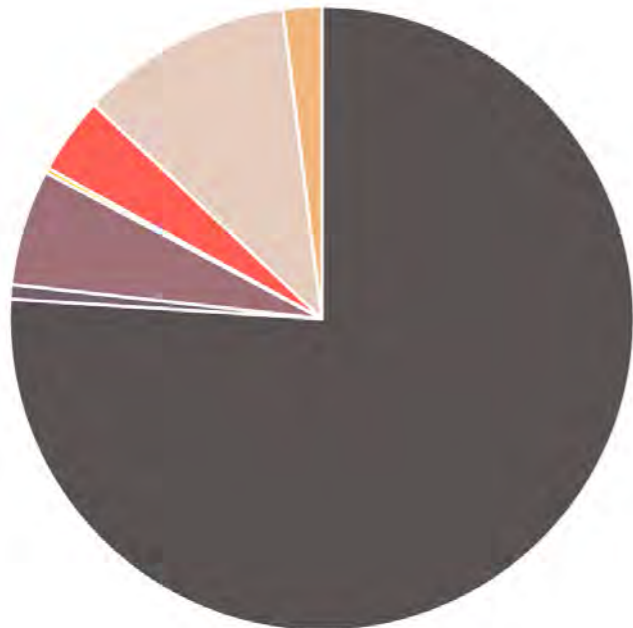


Total Carbon Emissions of **All Global New Construction** from 2020-2050

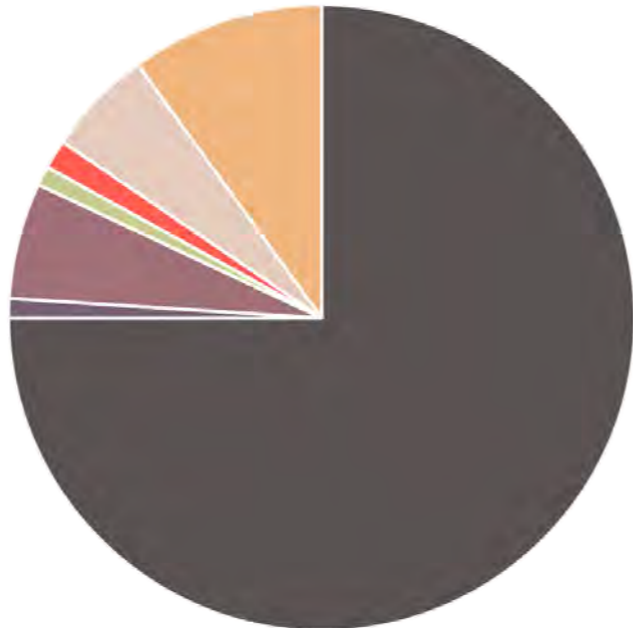
Business as Usual Projection



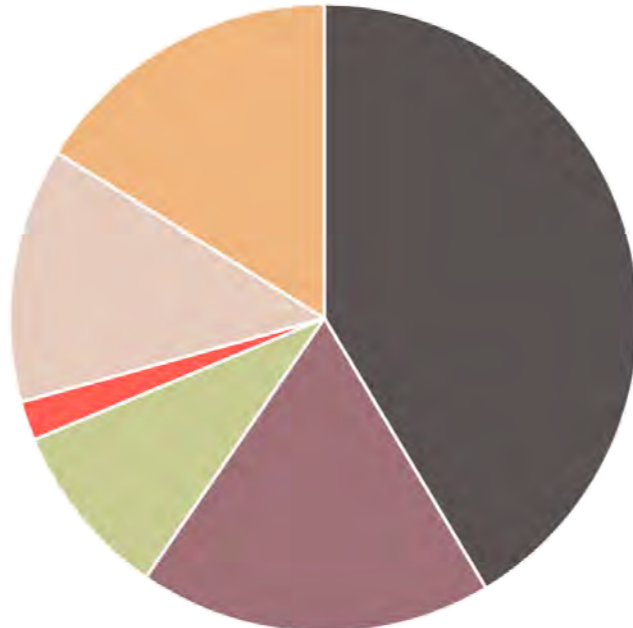
Embodied Carbon in Buildings by Material Category (GWP)



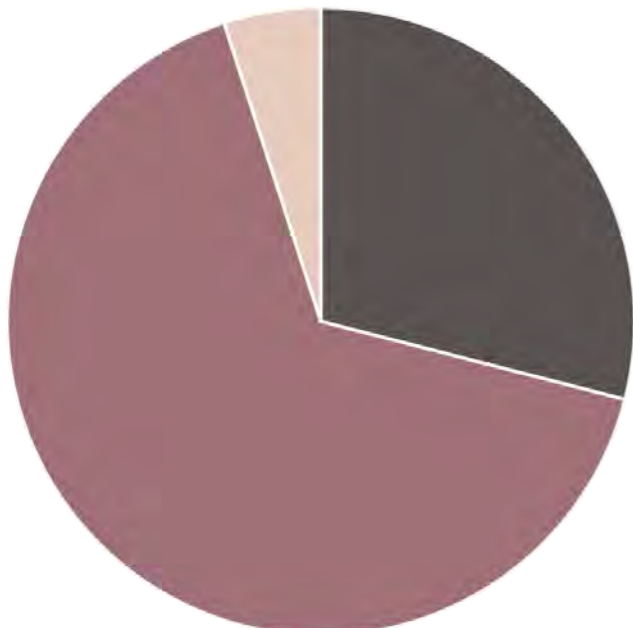
6 story mixed-use residential concrete structure



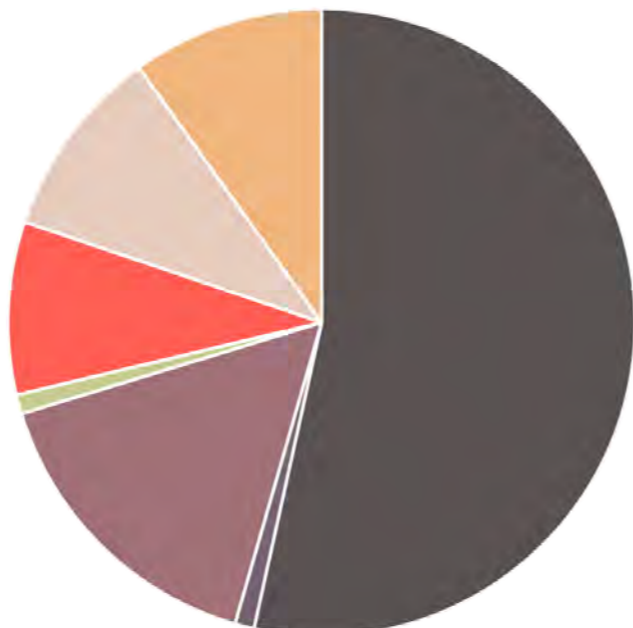
3 story (55,000 GSF) lab+research facility concrete structure



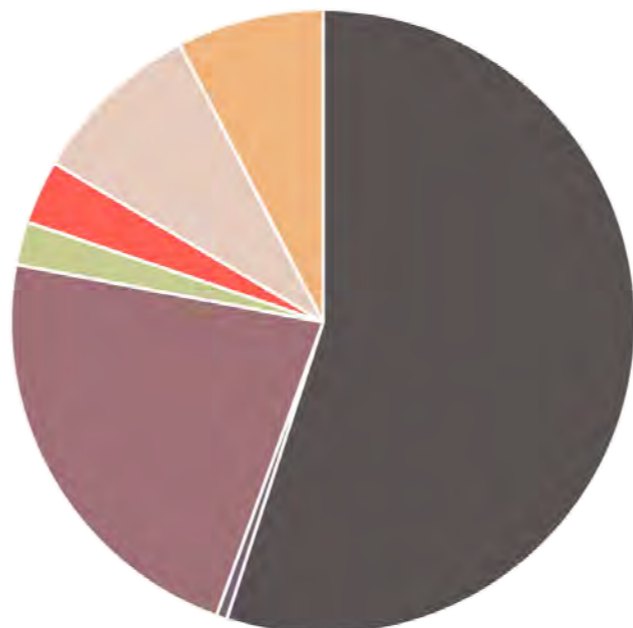
6 story residential mixed concrete and wood structure



800k GSF commercial concrete and steel structure



4 story (140k GSF) academic use concrete structure



Averaged



Charts based on whole building LCA studies completed using Tally



HOW DO WE REDUCE EMBODIED CARBON?

Reducing Embodied Carbon in Design and Policy

Prescriptive Path

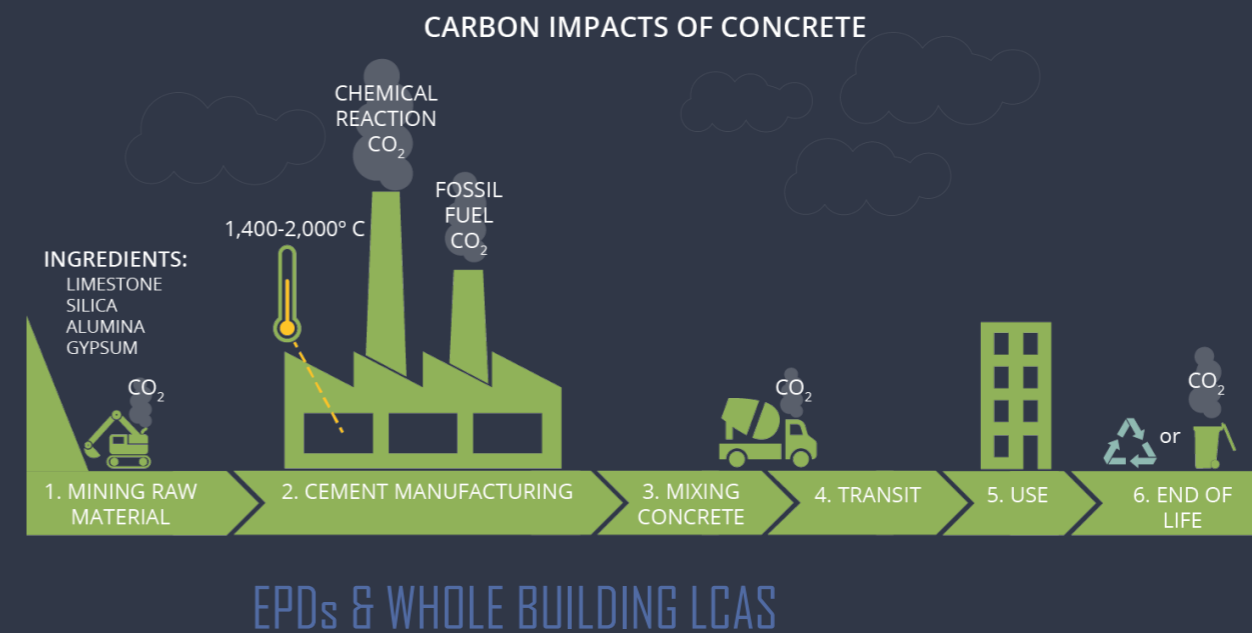


USE DRY KILN WITH PREHEATER AND PRECALCINER



UTILIZE CARBON INJECTION

Performance Path





CARBON SMART

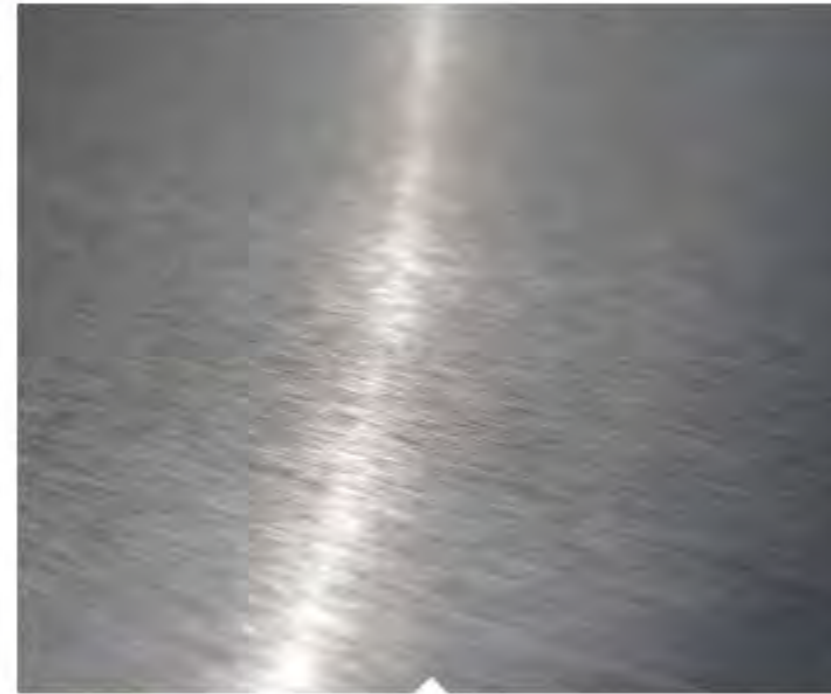
MATERIALS PALETTE™

HIGH-IMPACT MATERIALS

Predominant building materials with high-impact potential for emissions reductions



CONCRETE



STEEL



WOOD



INSULATION

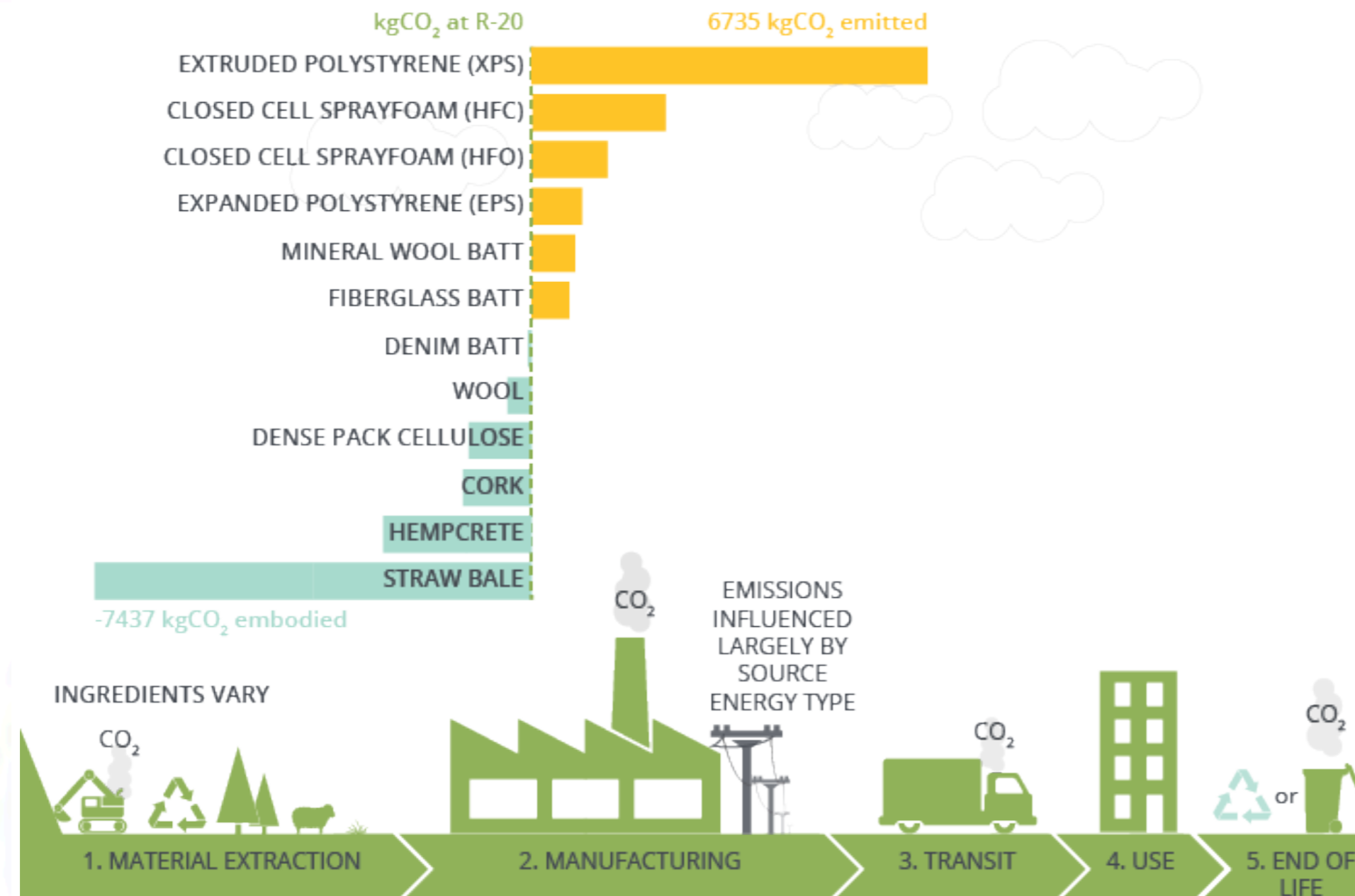
CARBON-SMART MATERIALS

Low carbon/carbon sequestering materials



INSULATION

CARBON IMPACTS OF INSULATION



CARBON IMPACT OF INSULATION

Insulation choices greatly affect the carbon footprint of the building in terms of embodied carbon and operational carbon emissions. Insulation can be either a significant contributor to the embodied carbon footprint of the building, or a carbon sink, depending on the choice of materials used. When selecting insulation, operational performance considerations (thermal performance, climatic requirements, air leakage rates, moisture resistance) should be balanced with embodied carbon targets.

Using natural materials and blown-in applications are the best way to reduce the embodied carbon of insulation.

CARBON SMART ATTRIBUTES FOR INSULATION

Specify insulation materials that naturally sequester carbon

Materials such as wood, straw, clay-straw, hemp, cork, and sheep's wool naturally sequester carbon and store it over their useful life. Using these materials can reduce the carbon footprint of your building.

Specify blown-in insulation instead of rigid and spray foams insulation

Blown-in fiberglass and cellulose insulation have a significantly lower embodied carbon impact than rigid insulation and spray foams. Also, if not properly installed (tacked to studs or rafters), some batt insulations can slump over time and spray foam can crack with building movement or settling, creating a thermal bridge and potentially leading to moisture condensation and wall assembly degradation. Using high density blown-in (non-foam) insulation (over 3.5 pcf) can help minimize thermal bridging, minimize embodied carbon, and improve the operational performance and lifespan of a building.

Avoid Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), Polyisocyanurate (Polyiso), Structurally Insulated Panel Systems (SIPS) with foam insulation, and spray foam, where climate allows

All of the insulations listed above are petroleum-based products that require significant energy to manufacture resulting in a high-embodied carbon footprint. Where climate and project requirements allow, specify lower carbon alternatives.

DESIGN GUIDANCE

Specify different insulations for different uses

Exterior rigid insulation is often used as a layer of continuous insulation to prevent thermal bridging and provide air-tightness if used as an air barrier (with taped seams). However, due to its significant carbon footprint, use rigid insulation sparingly. In a wall assembly, consider mineral wool as a lower-carbon alternative to XPS, EPS, and Polyiso. Under the slab, consider EPS over XPS.

Protect insulation from heat and water

Moisture and high temperatures are the biggest threats to the durability of insulation materials. Many foam insulations degrade with exposure to heat, and cellulose and fiberglass insulations are susceptible to water damage from rain, leaks, and/or vapor condensation. Ensure that wall assemblies are adequately designed and that all insulation is installed according to the manufacturer's instructions.

ACKNOWLEDGED CHALLENGES, QUESTIONS & UNKNOWNNS

- Though avoiding the use of rigid insulations and spray foams where possible reduces carbon emissions, this is not possible in all climates. In some climates, rigid insulation is required for dew point (condensation) considerations.. However, some recent projects in marine climates have successfully utilized mineral wool instead of rigid insulation¹.
- EPS is better than XPS at this time, though it has a significant embodied carbon impact. A better, lower-carbon alternative should be developed.
- A deeper wall assembly may be necessary when using materials that naturally sequester carbon.
- Use of recycled content is largely driven by availability – try to use recycled content when locally available to avoid emissions from raw material manufacturing and transportation.
- Embodied carbon footprints (within EPDs) are available for several naturally low-carbon or carbon sequestering materials. However, further research should be completed to ensure that the Life Cycle Assessments for these products account for agricultural practices.

RESOURCES

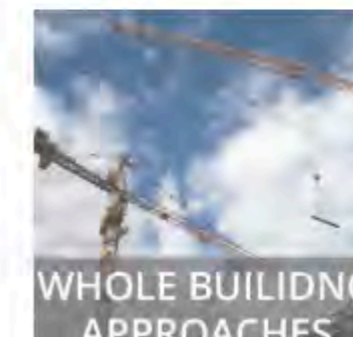
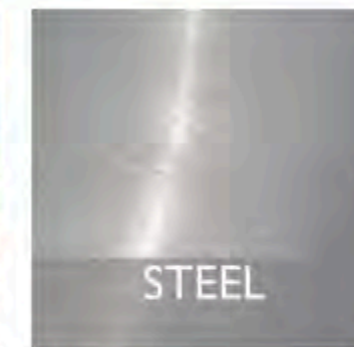
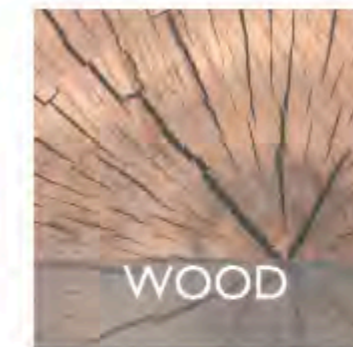
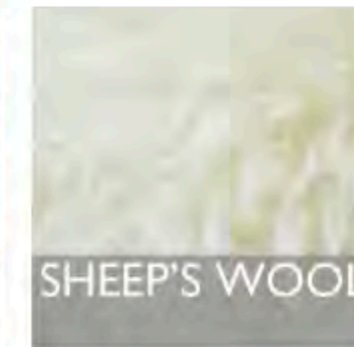
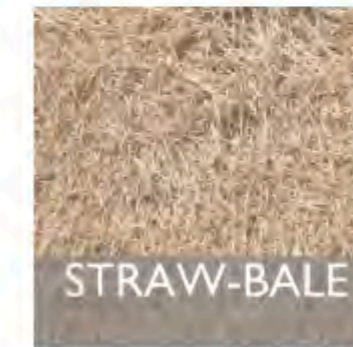
1 | [Orchards at Orenco Phase I and II](#)

Other Resources:

[Table of embodied energy or primary energy of materials](#), Enrique Azpilicueta Astarloa, PhD,

[Making Better Buildings](#), Chris Magwood, 2016

SEE ALSO



CARBON SMART **STEEL**



Use steel that comes from electric arc furnaces (EAFs)

EAFs produce less than half as much CO₂ as basic oxygen furnaces (BOFs).
Use structural steel that come from EAFs instead of steel from BOFs
whenever possible.

CARBON SMART **STEEL**



Use recycled steel

Virgin steel can have an embodied carbon footprint that is up to five times greater than high-recycled content steel. EAFs use an average of 93% recycled content, where BOFs use an average of 25% recycled content. Use high-recycled content steel whenever possible.

CARBON SMART **STEEL**



Power EAFs with carbon-free renewable energy

Basic oxygen furnaces (BOFs) burn coal or natural gas to create steel. EAFs are powered by electricity and therefore have the ability to be powered using renewable energy sources.

CARBON SMART **STEEL**



Examples

EVRAZ Steel is the single biggest consumer of Xcel Energy in Colorado. In 2018, they signed a deal for 240 MW of solar capacity, ensuring a close proximity to a clean, low-cost energy source.

Nucor Steel's Washington plant uses EAFs and is powered by Seattle's predominantly hydro-electric grid.

CARBON SMART WOOD



Don't specify wood harvested from old growth forest

The ecosystem- and carbon-impacts of harvesting old growth forests and rainforests are significant. A significant portion of carbon sequestered by trees is pushed into the soil around the tree. Harvesting old growth forests and rainforests greatly disturbs the ground, releasing much of that sequestered carbon.

CARBON SMART WOOD



Specify timber from sustainably managed forests

Forest management practices can greatly influence the carbon footprint of a wood product, so specify wood and wood products from sustainably managed forests.

WOOD QUESTIONS



More questions than answers...

Amount of carbon stored

Impact of forest management practices

Material switching to wood

Ability to scale to meet global population growth

Climate and land use implications of scaling mass timber production

materialspalette.org





CARBON' POSITIVE 20

INTERNATIONAL CONFERENCE & EXPO

Los Angeles, March 2-4, 2020



Thank you

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