

Better Design Through Embodied Carbon

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Learning Objectives

- Calculate embodied carbon
- Learn instances when the embodied carbon of systems should not be compared
- Understand pitfalls related to estimates of embodied carbon
- Identify sources and tools for embodied carbon data

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Big Picture

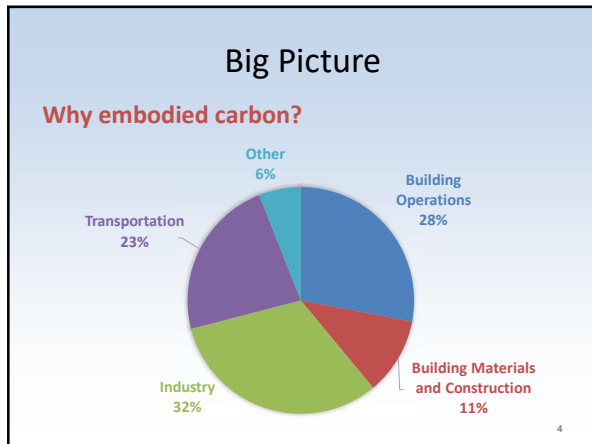
A common starting point

- Climate change is real
- Need to reduce greenhouse gas emissions
- Urgency
- "Time value" of carbon



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Big Picture

Before we get into the weeds

- During design, not only greenhouse gas emissions
 - Water
 - Waste
- Reduction in most sectors will result from greening the energy grid

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Definitions—Acronyms

- CO₂e = carbon dioxide equivalent
- EPD = environmental product declaration
- GWP = global warming potential
- LCA = life-cycle assessment
- PCR = product category rules

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Definitions—Terminology


- Life-cycle stages

Construction works life cycle information within the system boundary

A1 - A3 PRODUCTION Stage (Mandatory)			A4 - A5 CONSTRUCTION Stage		B1 - B7 USE Stage					C1 - C4 END-OF-LIFE Stage			
A1	A2	A3	A4	A5	B1	B2	B3	B4*	B5	C1	C2	C3	C4
Extraction and upstream production.	Transport to factory.	Manufacturing.	Transport to site.	Installation.	Use.	Maintenance (incl. production, transport and disposal of necessary materials).	Repair (incl. production, transport and disposal of necessary materials).	Replacement (incl. production, transport and disposal of necessary materials).	Refurbishment (incl. production, transport and disposal of necessary materials).	De-constructive / demolition.	Transport to waste processing or disposal.	Waste processing.	Disposal of waste.
			Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario
					B6 Operational energy use								
					Scenario								
					B7 Operational water use								

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Definitions—Terminology



Embodied carbon


- aka carbon footprint
- aka carbon dioxide emissions
- aka carbon dioxide equivalent emissions
- aka greenhouse gas emissions
- aka...

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Definitions—Terminology

Embodied carbon



For simplicity in this report, we are focusing on *initial embodied carbon*—the impacts associated with extracting, manufacturing, and transporting materials to the jobsite. “Carbon” is used to indicate all greenhouse gas emissions, not just carbon dioxide.

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Definitions—Terminology

Embodied carbon



The embodied carbon from materials such as steel and cement, and from the manufacturing and transportation of products, are **not reflected in buildings' operational carbon emissions**. The 2030 Challenge for Embodied Carbon addresses these emissions by setting reduction targets for embodied carbon and thereby allows architects to make informed decisions when specifying building materials.

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Definitions—Terminology

Embodied carbon

Embodied carbon (kgCO₂e): Carbon emissions associated with:

- extraction and manufacturing of materials and products
- in-use maintenance and replacement
- end of life demolition, disassembly and disposal including transportation relating to all three⁹.



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Definitions—Terminology

Embodied carbon

- ISO 14067-18, *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification*

sum of *GHG emissions* and *GHG removals* in a *product system*, expressed as *CO₂ equivalents* and based on a *life cycle assessment* using the single *impact category* of climate change

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Life-cycle Assessment (LCA)

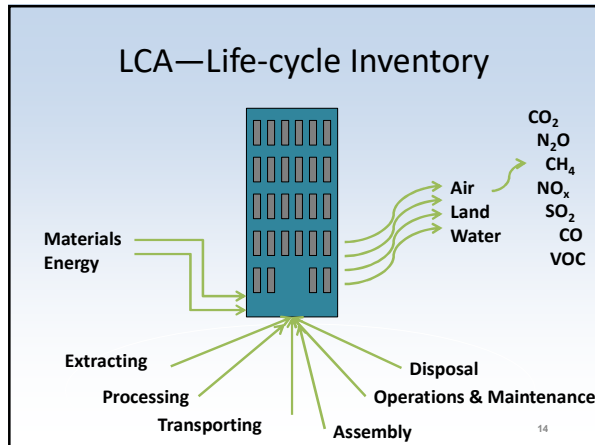


- Goal and scope
- Life-cycle inventory
- Life-cycle impact assessment
- Interpretation

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LCA—Life-cycle Inventory



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LCA—Life-cycle Impact Assessment

Characterize LCI flows into impact categories

- **Global Warming Potential**
- Acidification Potential
- Eutrophication Potential
- Photochemical Ozone Creation Potential
- Ozone Depletion Potential
- Ecological Toxicity
- Habitat Alteration
- Many more....

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LCA—Product Labels

- LCA a good tool, but complicated
- Difficult to know best choice.
- **Simplified** summary = labels



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Environmental Product Declarations (EPDs)

- ISO 21930, *Sustainability in buildings and civil engineering works — Core rules for environmental product declarations of construction products and services*
- Based on LCA and PCR
- Peer reviewed



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EPD—Product Category Rules

PCR are:

- Created or administered by a program operator
- Are separated by product category
- Sets a declared or functional unit



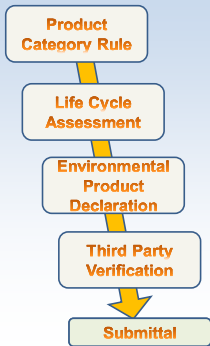
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EPD—Product Category Rules

PCR set rules for LCA:

- Goal and Scope
 - Life-cycle stages
- Cut-off rules for LCI
- Method and categories in impact assessment



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EPD—Embodied Carbon

- Commonly used for embodied carbon data
- Not an LCA
- When comparing: Need same PCR
- Understand what's NOT included
- Best to compare *within* product category, *not across* product category

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EPD—Comparison Example

- Ready-mix concrete versus precast concrete

Environmental Product Declaration

NRMCA
NATIONAL READY MIXED CONCRETE ASSOCIATION

NRMCA MEMBER INDUSTRY-AVERAGE EPD FOR READY MIXED CONCRETE

Environmental Product Declaration (EPD) for Precast Concrete CPCI PCI

According to ISO 14025 and ISO 21930

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EPD—Comparison Example

PCR

- Ready-mix concrete
 - ISO 21930:2017 (core PCR)
 - NSF International Product Category Rule (PCR) for Concrete Version 1 (February 22, 2019) serves as the sub-category PCR
- Precast concrete
 - ASTM International, Product Category Rules For Preparing an Environmental Product Declaration For Precast Concrete, March 2015.

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EPD—Comparison Example

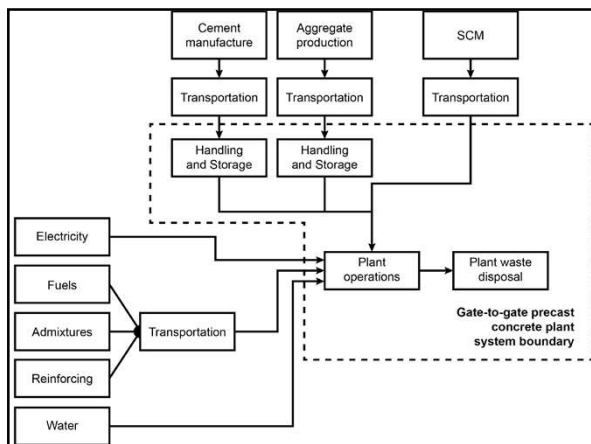
Life-cycle stages

- Looks the same on the surface
- Ready-mix concrete
 - Cradle-to-gate: A1-A3
- Precast concrete
 - Cradle-to-gate: A1-A3



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EPD—Comparison Example

Life-cycle stages

- Ready-mix concrete
 - Cradle-to-gate: A1-A3

System boundary

The scope of this EPD is cradle-to-gate and considers the following life cycle stages:

- **A1 - Raw Material Supply:** Includes all upstream processes related to extraction, handling, and processing of the raw materials and intermediate component products as well as fuels used in the production of concrete. Component products include cement, supplementary cementitious materials, aggregate (coarse and fine), water, admixtures and other materials or chemicals used in concrete mixtures.
- **A2 - Transportation:** Accounts for the transportation of all input materials and fuels from the supplier to the gate of the concrete plant.
- **A3 - Manufacturing (Core Processes):** Includes all core processes and the energy and water used to store, move, batch and mix the concrete and operate the concrete plant as well as the transportation and processing of wastes from these core processes.

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EPD—Comparison Example

Life-cycle stages

- Precast concrete

The Product Stage includes the following processes [1]:

- A1 - Extraction and processing of raw materials, including fuels used in product production and transport within the manufacturing process (A3);
- A2 - Average or specific transportation of raw materials from the extraction site or source to manufacturing site, inclusive of empty backhauls (where applicable);
- A3 - Manufacturing of each precast product including all energy and materials required and all emissions and wastes produced;
- Average or specific transportation from manufacturing site to recycling/reuse/landfill for pre-consumer wastes and unutilized by-products from manufacturing, including empty backhauls (where applicable);
- Final disposition of pre-consumer wastes inclusive of transportation;

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EPD—Comparison Example

Comparison warnings

- Ready-mix concrete
 - “Comparison based on LCA A1-A3 data, shall be made only if the same secondary data sets, and all subsequent life cycle stages are equivalent for both EPDs.”
 - “If concrete EPDs are used to compare two different concrete mixes, the functional units must be the same. Additionally, the following conditions must be met:
 - The concrete mixes have the same...structural, thermal, and exposure properties
 - for product specific EPD comparisons, results for transportation reflect actual transportation distances .”

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EPD—Comparison Example

Comparison warnings

- Precast concrete
 - “...Only EPDs prepared from cradle-to-grave life-cycle results and based on the same function, reference service life, and quantified by the same functional unit, and meeting all the conditions in ISO 14025, Section 6.7.2, can be used to assist purchasers and users in making informed comparisons between products.”
 - “EPDs based on cradle-to-gate information modules shall not be used for comparisons unless using a functional unit and complying with all of the requirements set out in ISO 14025, Section 6.7.2 and ISO 21930, Section 5.6, when the product is used in buildings. EPDs based on a declared unit shall not be used for comparisons.”

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EPD—Comparison Summary

- Not an LCA
- When comparing: Need same PCR
- Best to compare *within* product category, *not across* product category
- Same secondary data sets, same methodology, same tools, to name a few.

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Case Study

- Two phases:
 - Cradle-to-gate
 - Cradle-to-grave
- Comparative assertion
- Five envelope systems
- Three structural systems

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Case Study

- Typical 5-story commercial office building
- Gross floor area 5017 m²
- Story heights 4.6 m (first) and 3.7 m (all)
- Window-wall ratio 0.40
- Conditioned space for 130 people
- 73-year service life

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Case Study

Four climate zones
Ten environmental indicators

- global warming potential,
- total primary energy,
- acidification potential,
- respiratory effects,
- eutrophication potential,
- photochemical
- smog creation potential,
- solid waste,
- abiotic resource depletion,
- water use, and
- ozone depletion potential.

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Case Study

Cradle-to-gate

- Most informative for production processes
- Identified environmental hot spots

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Case Study

Cradle-to-gate

- Environmental hot spots:
 - Portland cement usage
 - Transportation distances
- Other important factors
 - Water usage
 - Insulation amounts (ODP)

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Case Study

Envelope System	Precast Structure	Cast-in-place Structure	Steel Structure
Curtain Wall	CW-P	CW-C	CW-S
Brick and Steel Stud	S-P	S-C	S-S
Precast	P-P	P-C	P-S
Insulated Precast	Pi-P	Pi-C	Pi-S
Insulated Precast with Brick Veneer	Pib-P	Pib-C	Pib-S

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Case Study

- As we go through slides:
 - Scale: not the same on both graphs
 - Relative values (cradle-to-grave COV < 2%)
 - One building, one set of conditions

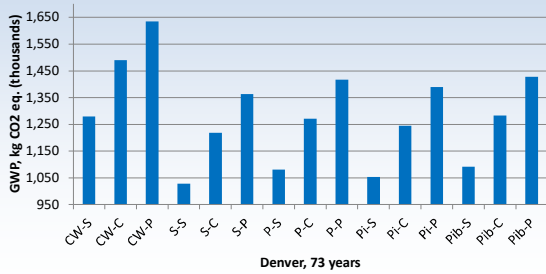
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Global Warming Potential (GWP)

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Case Study—GWP - Denver

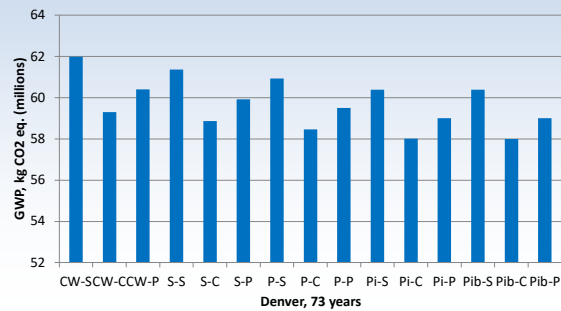
- Cradle to Gate



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Case Study—GWP - Denver

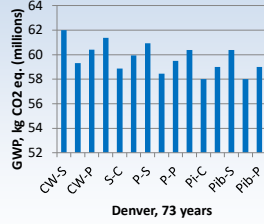
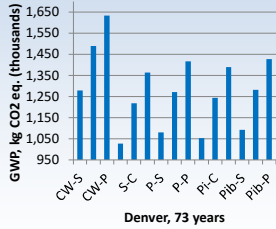
- Cradle to Grave



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Case Study—GWP - Denver

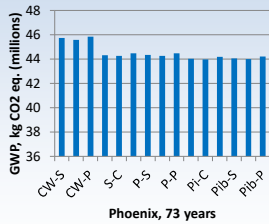
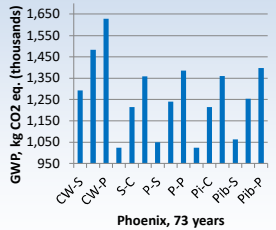
- Cradle to Gate
- Cradle to Grave



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Case Study—GWP - Phoenix

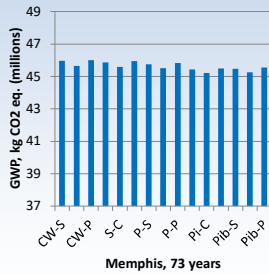
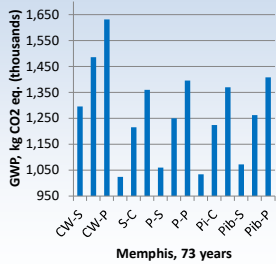
- Cradle to Gate
- Cradle to Grave



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Case Study—GWP - Memphis

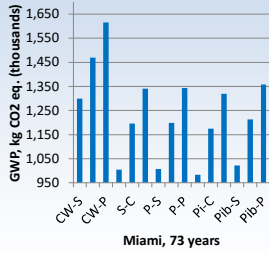
- Cradle to Gate
- Cradle to Grave



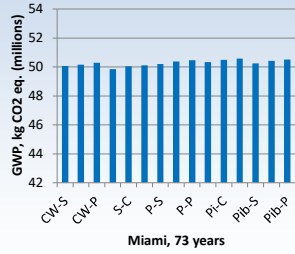
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Case Study— GWP - Miami

- Cradle to Gate



- Cradle to Grave



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Case Study—Conclusions

- Findings:

- Use stage (Operating energy) has the greatest environmental impact for any structure/enclosure combination (about 96%)
- The coefficient of variation (COV) among structure/enclosure combination for a given climate zone was 2% or less

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Embodied Carbon—Data



- Primary data
 - from manufacturers
 - from industry average
- Secondary data
 - from databases

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Embodied Carbon—Data

No matter where you get data, ask yourself these questions:

- What life-cycle stages are included?



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Embodied Carbon—Data

- What life-cycle stages are included?

Construction works life cycle information within the system boundary

A1 - A3 PRODUCTION Stage (Mandatory)			A4 - A5 CONSTRUCTION Stage		B1 - B7 USE Stage					C1 - C4 END-OF-LIFE Stage				
A1	A2	A3	A4	A5	B1	B2	B3	B4*	B5	C1	C2	C3	C4	
Extraction and upstream production	Transport to factory	Manufacturing	Transport to site	Installation	Use	Maintenance (incl. repair, transport and disposal of necessary materials)	Repair (incl. production, transport and disposal of necessary materials)	Replacement (incl. production, transport and disposal of necessary materials)	Refreshment (incl. production, transport and disposal of necessary materials)	De-contraction / Demolition	Transport to water processing or disposal	Water processing	Disposal of waste	
Scenario			Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	
					B6 Operational energy use									
					Scenario									
					B7 Operational water use									
					Scenario									

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Embodied Carbon—Data

No matter where you get data, ask yourself these questions:


- What life-cycle stages are included?
- What characterization method was used?
- How old is the data?
- What underlying standards are used?
- Which tool was used for calculating?

Calculating the A1-A5 emissions (cradle to practical completion) is the minimum scope for a structural embodied carbon calculation (substructure and superstructure).

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Embodied Carbon—Tools

- LCA software
- LCA-based software
- Databases





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Embodied Carbon—Tools

LCA-based software

- Tally
- Athena Impact Estimator for Buildings





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Embodied Carbon—Tools

LCA-based software—Tally


- Plug-in to BIM
- Based on GaBi
- Cradle-to-grave tool
- Changes with design
- Allows real-time understanding of environmental hot spots



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Embodied Carbon—Tools

LCA-based software—Athena





- Free tool
- Based on Athena and U.S. LCI database
- Cradle-to-grave tool
- Limited choices
- Separate calculation

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Embodied Carbon—Tools

Databases

- Embodied Carbon in Construction Calculator (EC3)
- Sustainable Minds Transparency Catalog




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Embodied Carbon—Tools

Databases—EC3

- Embodied Carbon in Construction Calculator (EC3)
- Specification and procurement tool
- Only life-cycle stages A1-A3
- Use **only** for in-product-category comparisons



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Embodied Carbon—Tools

Databases—SM Transparency Catalog

- Sustainable Minds Transparency Catalog
- Database of available EPDs
- No comparability functionality
- Life-cycle stages determined by EPD
- Also includes HPD or other declarations



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Summary



- Life cycle stages matter
- Understand where data is coming from
- Comparability is not allowed without functional equivalence

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Websites

- <https://kierantimberlake.com/page/tally>
- <http://www.athenasmi.org/our-software-data/impact-estimator/>
- <https://www.buildingtransparency.org/en/>
- <https://www.transparencycatalog.com>

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Thank you!



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