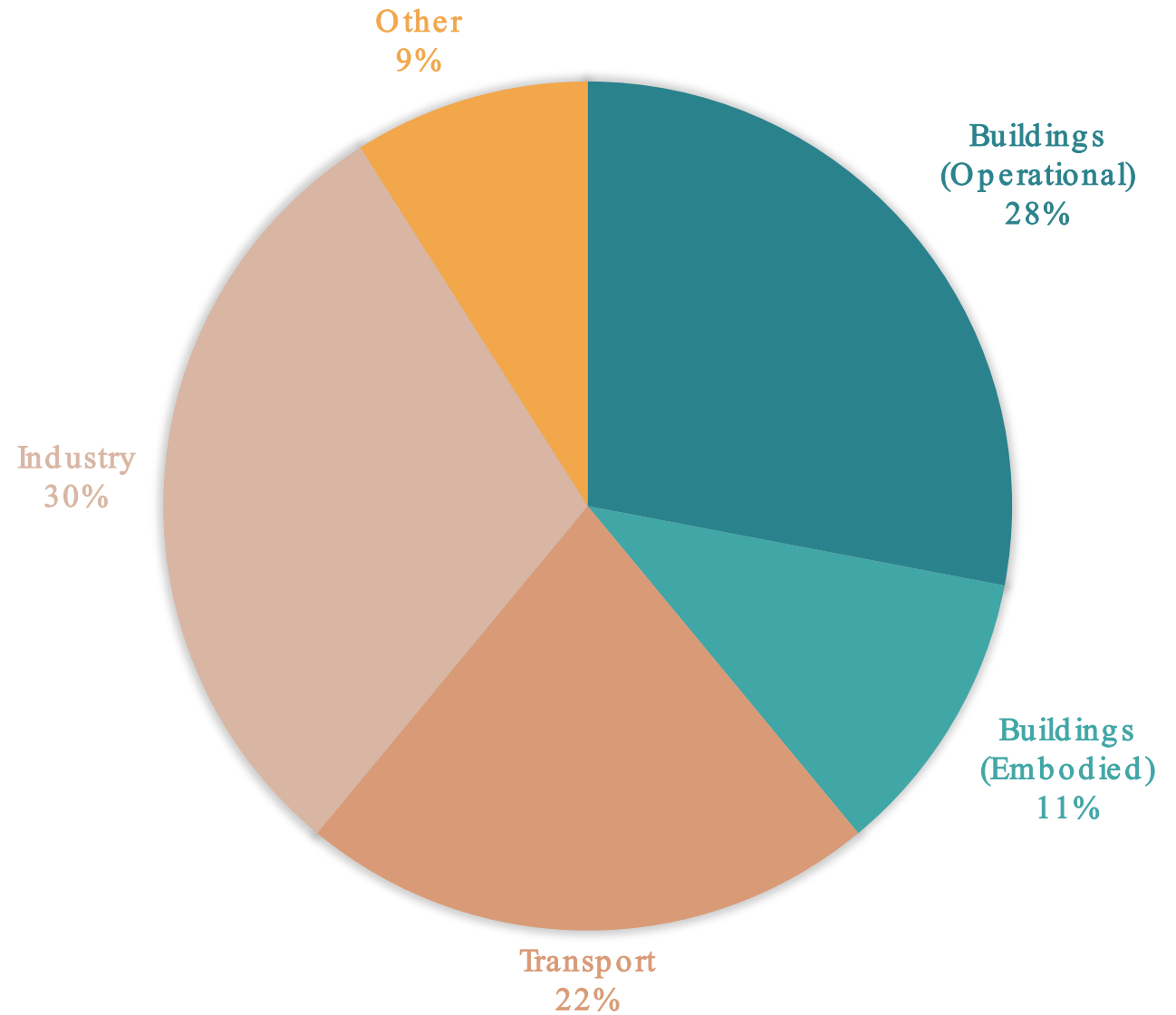




UNDERSTANDING EMBODIED CARBON

CARBON EMISSIONS

- Our buildings are responsible for around 40% of all global CO₂ emissions.



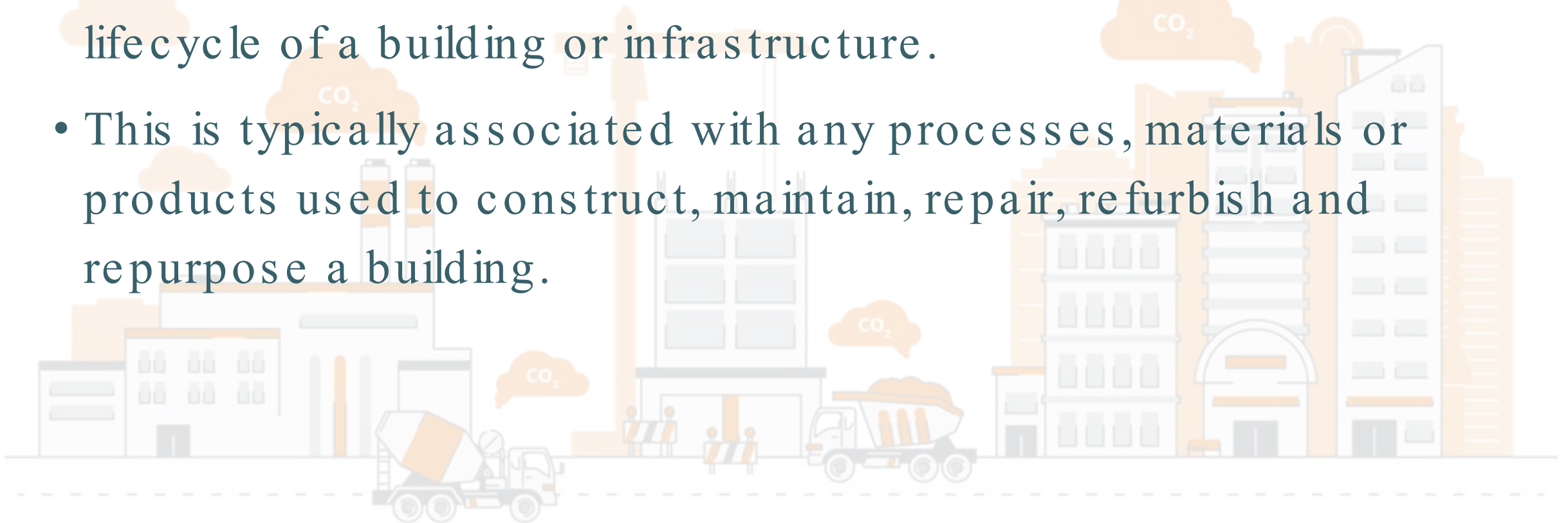
OPERATIONAL CARBON

- Operational carbon refers to 'the emissions associated with energy used to operate the building or in the operation of infrastructure'.
- This includes heating, hot water, cooling, ventilation, lighting systems, equipment and lifts.



EMBODIED CARBON

- Embodied carbon refers to the emissions associated with materials and construction processes throughout the whole lifecycle of a building or infrastructure.
- This is typically associated with any processes, materials or products used to construct, maintain, repair, refurbish and repurpose a building.



EMBODIED CARBON



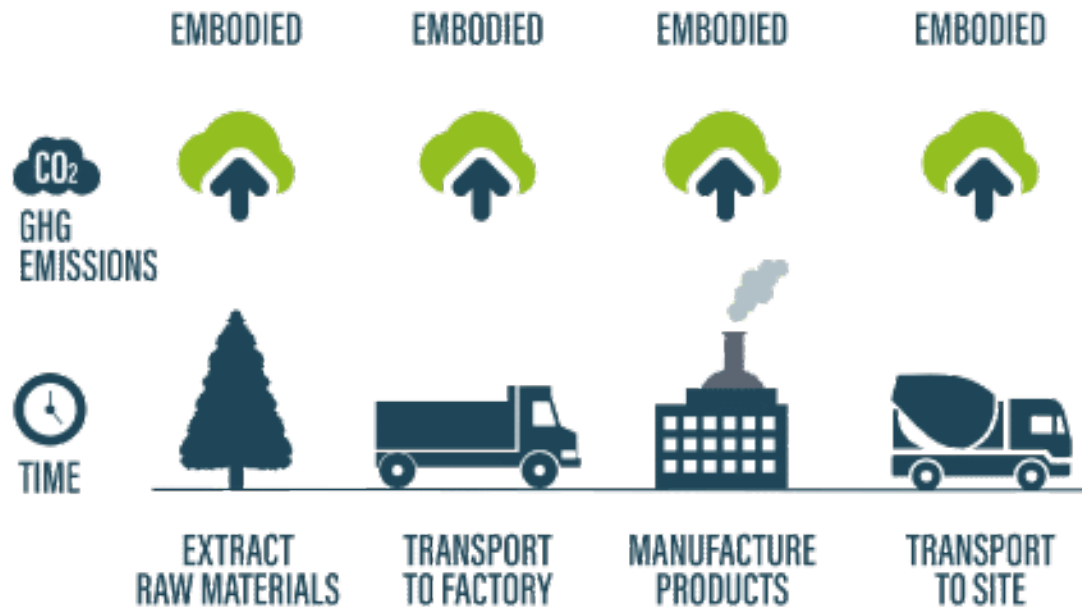
EMBODIED CARBON



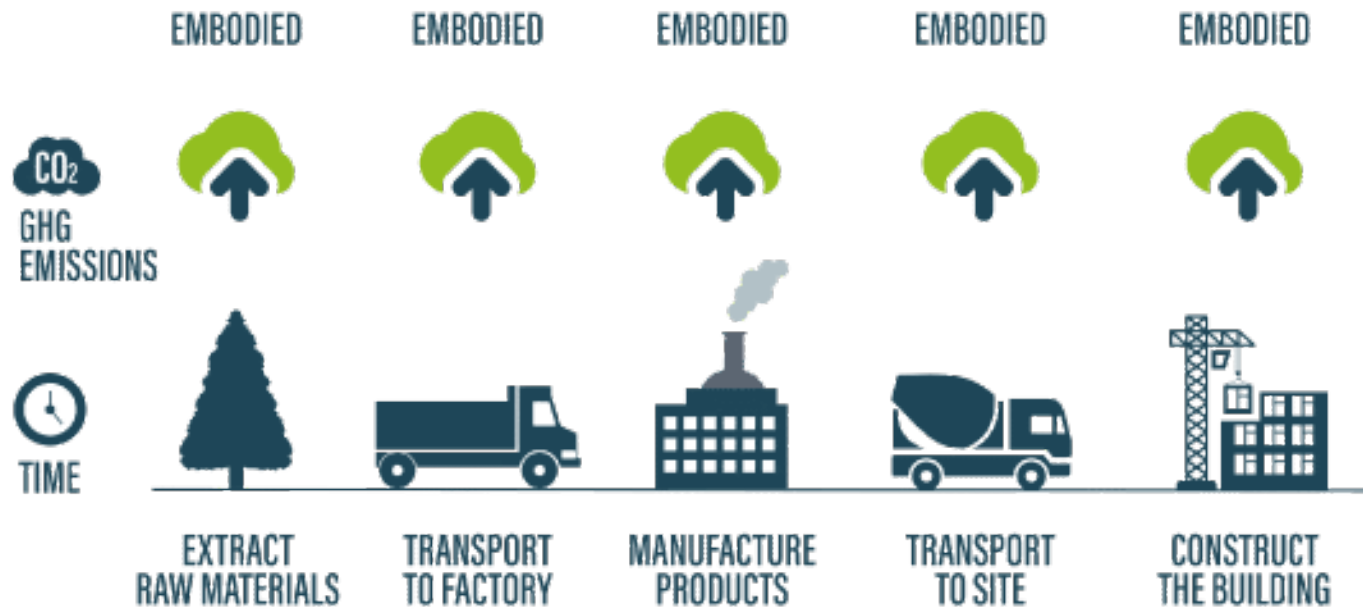
EMBODIED CARBON



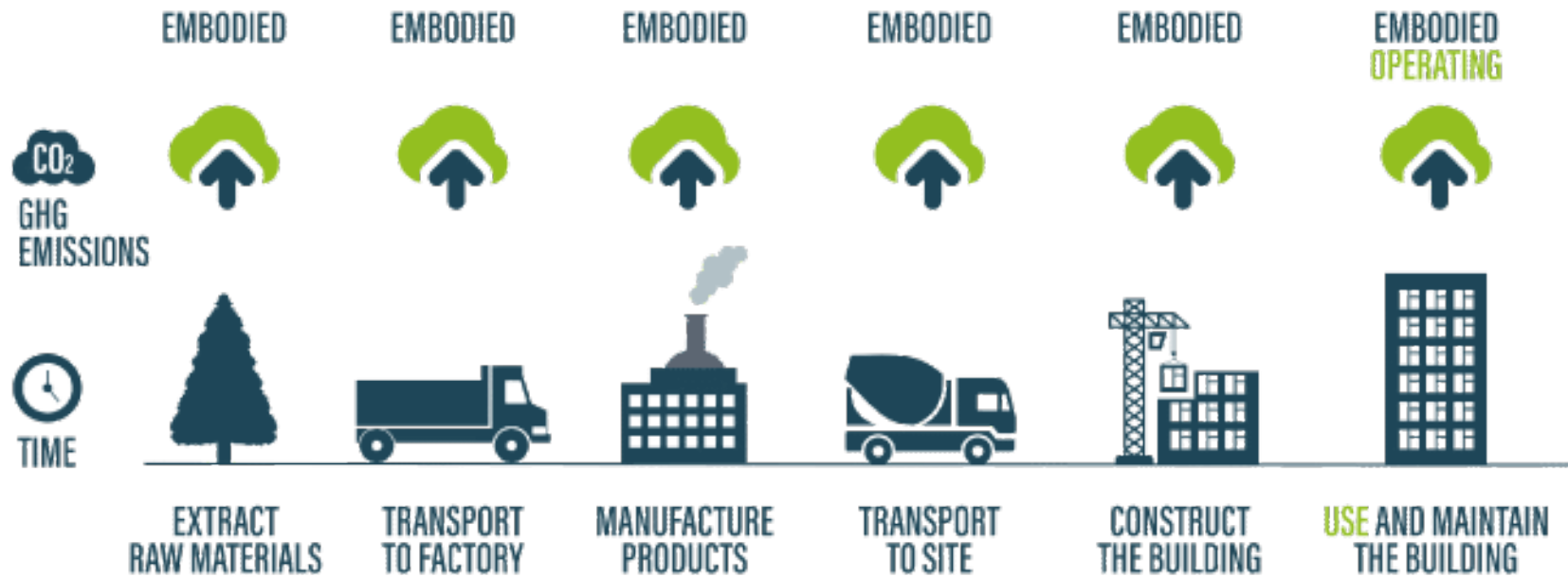
EMBODIED CARBON



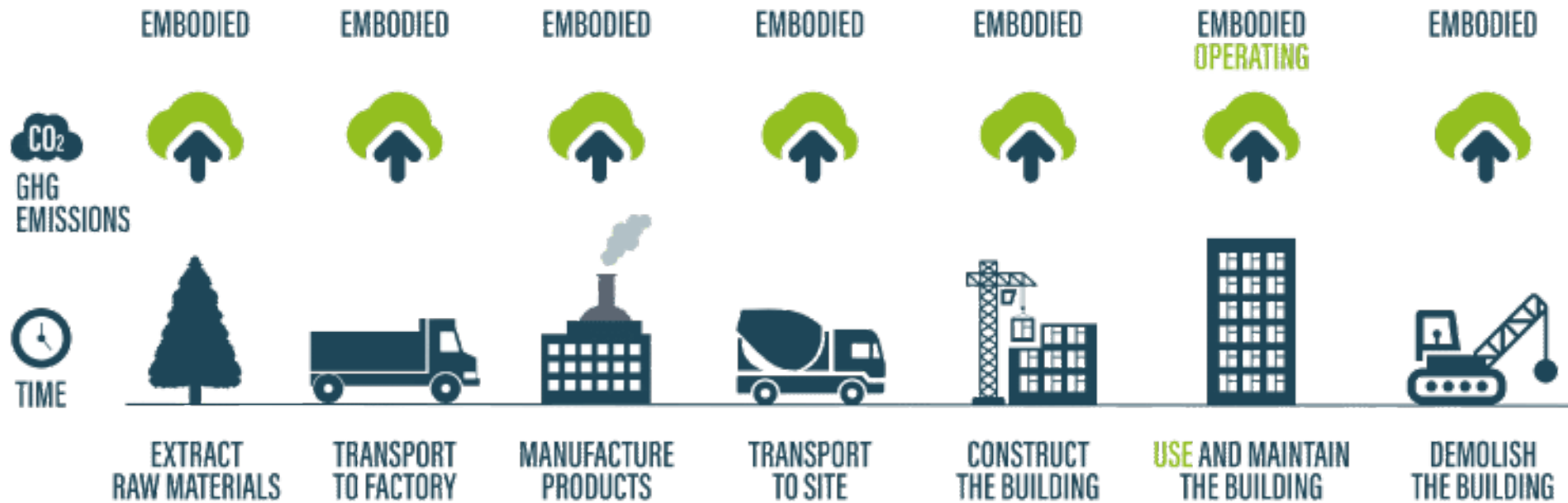
EMBODIED CARBON



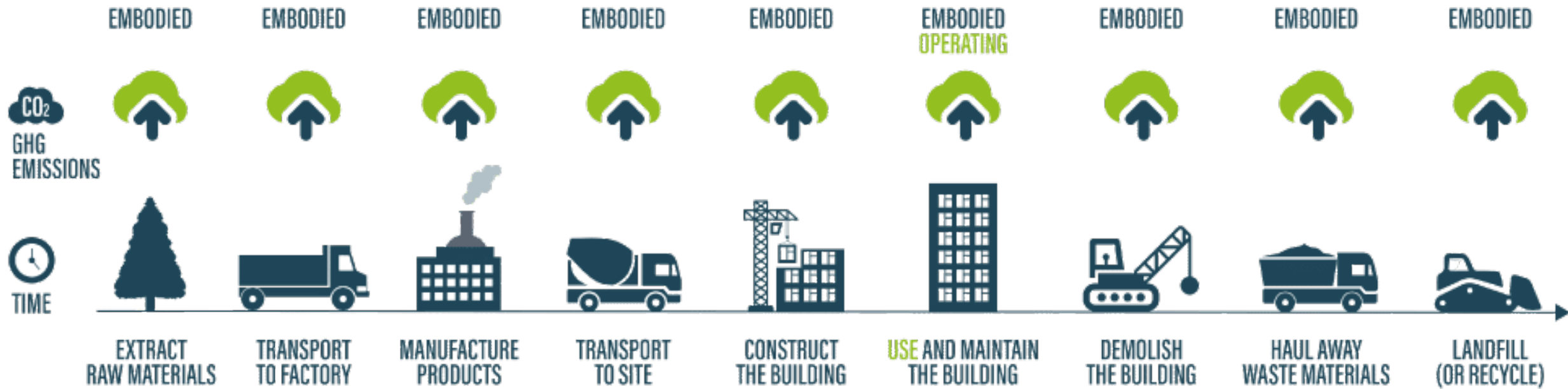
EMBODIED CARBON



EMBODIED CARBON



EMBODIED CARBON



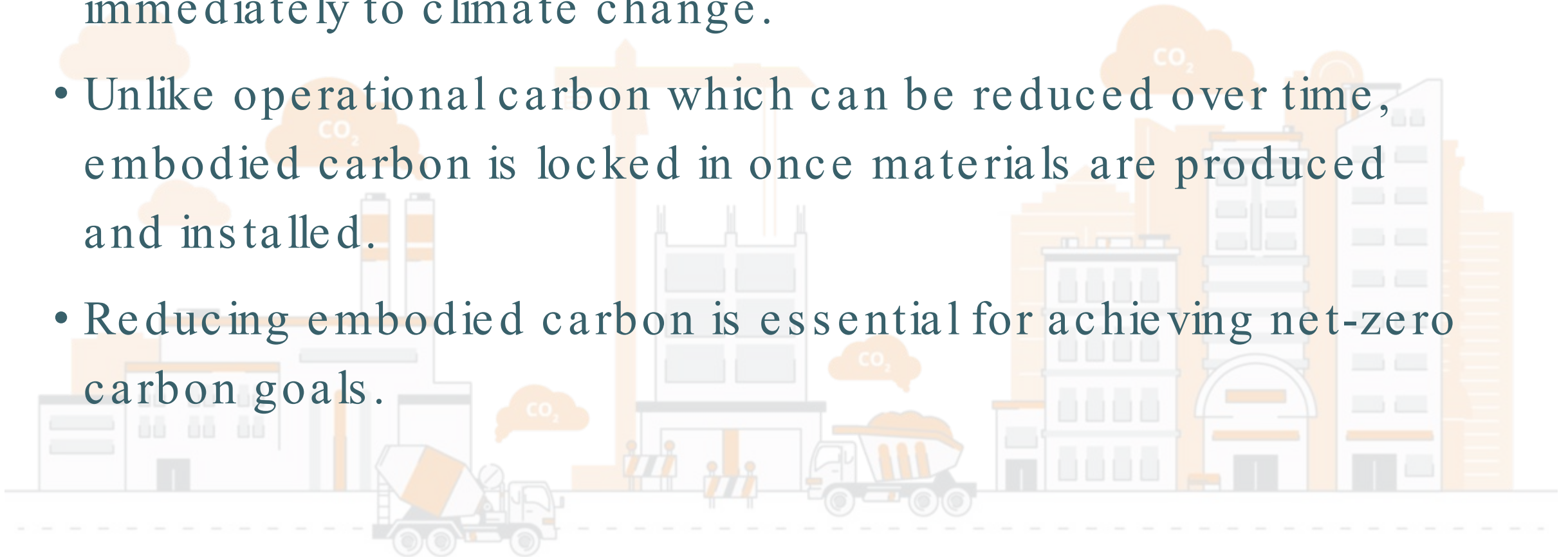
EMBODIED CARBON

Overall, Greenhouse gas emissions are predicted to follow a downward trend, largely due to the implementation of energy efficiency standards for new buildings, but embodied emissions are forecasted to increase.



CLIMATE CHANGE

- Embodied carbon is released upfront, contributing immediately to climate change.
- Unlike operational carbon which can be reduced over time, embodied carbon is locked in once materials are produced and installed.
- Reducing embodied carbon is essential for achieving net-zero carbon goals.



DECARBONISATION

Avoid

- The extraction and production of raw materials

Shift

- To low carbon earth- and bio-based building materials

Improve

- Methods to decarbonise conventional materials.

RESOURCE DEPLETION

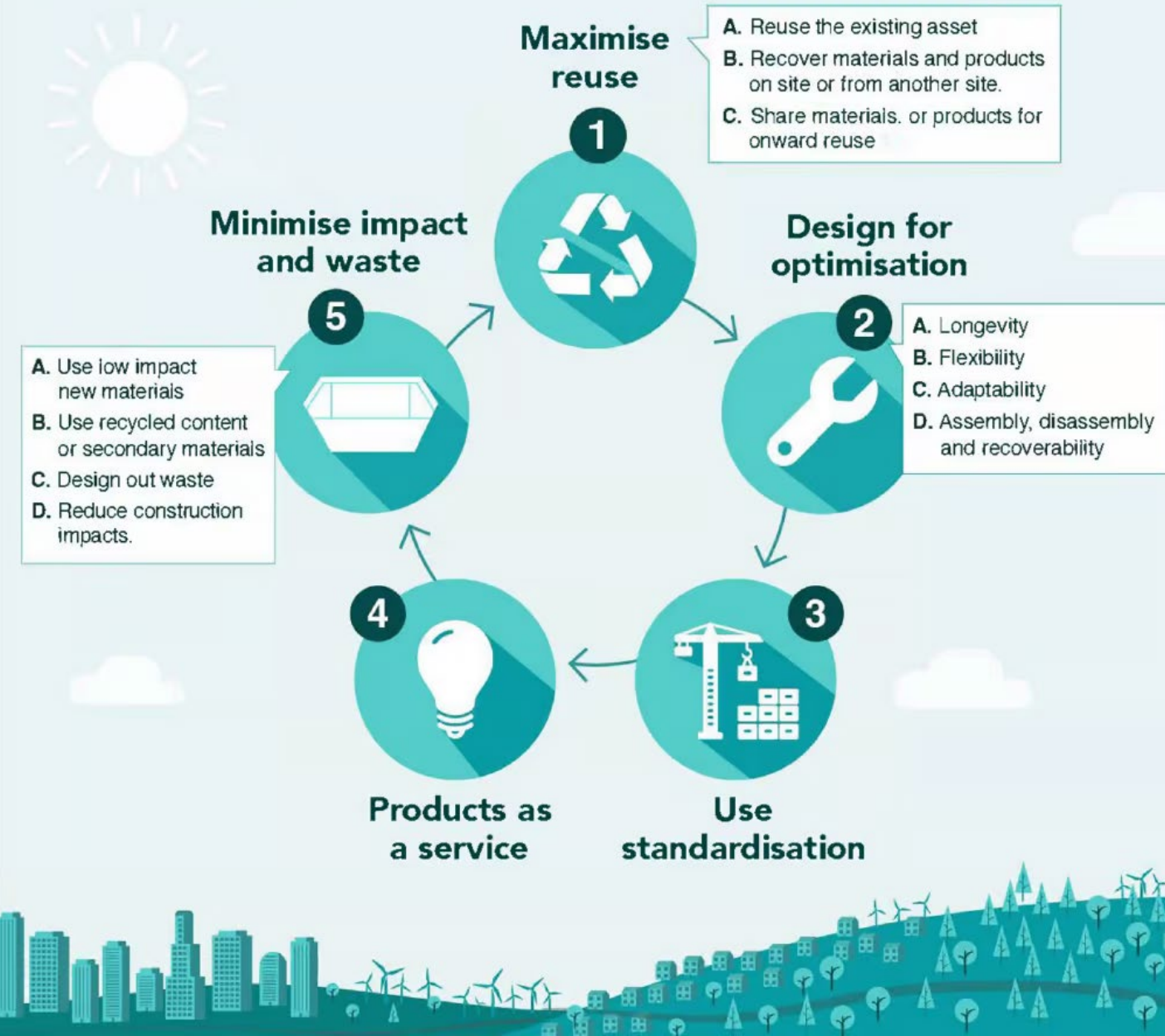
- The construction industry is responsible for 50% of global raw material extraction.
- Building materials account for half of the solid waste generated every year worldwide.



CIRCULAR ECONOMY

The circular economy in the construction industry focuses on minimising waste, maximising resource efficiency, and promoting sustainability by designing buildings and infrastructure with materials that can be reused, recycled, or repurposed.

Circular economy principles for construction



REUSE, REFURBISH AND REPURPOSE

Aim:

Reusing an entire asset
or reusing a significant
proportion of the existing
asset.



REUSE, REFURBISH AND REPURPOSE

Aim :

Incorporating reuse elements and materials that have been recovered from the existing site, or from another site, into the new development



DESIGN BUILDINGS FOR OPTIMISATION

Aim:

To create a built asset with well-defined long-term needs, while being durable, resilient or able to cope with societal and environmental change.

It will require little modification/no replacement of parts, due to its 'loose fit', generous proportions and readiness for alternative technologies

DESIGN BUILDINGS FOR OPTIMISATION

Aim:

To balance the needs of the present with how those needs will change in the future and to enable change through frequent reconfiguring including reconfiguration of non-structural parts



DESIGN BUILDINGS FOR OPTIMISATION

Aim:

Products and services are designed to be assembled, deconstructed and reused or recycled on a part-by-part basis.



STANDARDISATION

Aim:

Designing and constructing buildings that apply standardised elements or modular designs for materials and products that enable a reduction in construction waste and easier reuse in next life



PRODUCTS AS A SERVICE

Aim:

Establish and promote a payment structure through which customers have unlimited access to resources but only pay for what is used, or for the result linked to their use.

This represents a transition from selling products to selling services

DESIGN AND CONSTRUCT RESPONSIBLY

Aim:

Any new materials specified in the development are low impact materials with little or no adverse effect on either the environment or on human health throughout its lifecycle.



DESIGN AND CONSTRUCT RESPONSIBLY

Aim:

To recognise and encourage the use of recycled content and secondary aggregates, thereby reducing the demand for virgin material and optimising material efficiency in construction.



DESIGN AND CONSTRUCT RESPONSIBLY

Aim:

To design out waste over the whole life cycle of the building, so there is minimal waste during the design, construction, deconstruction and next life of the built asset.



DESIGN AND CONSTRUCT RESPONSIBLY

Aim:

Ensure construction sites reduce on-site waste, including packaging.



TIMBER

- The built environment uses 38 per cent of the world's wood products.



TIMBER

- Increasingly, mass timber is becoming an attractive alternative to carbon-intensive concrete and steel due to its potential for scalability, sustainability, strength and flexibility in mid-rise urban buildings.



TIMBER

- Advances in timber building material technologies are making it possible to shift towards large-scale structural timber products, provided that the timber industries continue to innovate and are regulated for sustainable practices.



BAMBOO

- Bamboo is a fast-growing renewable resource that has witnessed significant advances as a scalable building material in the last two decades.



BAMBOO

- Progress in engineered bamboo has demonstrated structural performance like that of cross-laminated timber and steel.



BAMBOO

- However, the variability in species across regions requires investments in further development of low-cost and low-carbon construction methods, standards and certifications.

IMPROVE

- Cement can be decarbonised by reducing the clinker-to-cement ratio, increasing the share of cement alternatives
- Shifting to electric kilns powered by a decarbonised electric grid supplied with renewable energy
- Potentially strengthening concrete through carbon capture and utilisation during manufacturing.



IMPROVE

- In primary steel production, a shift from blast furnace to direct reduced iron technology
- Coupled with electric arc furnaces powered by renewable energy sources, offers the greatest emission reduction potential
- Increasing recycling efficiencies and carbon capture and storage



IMPROVE

- Plastics are used in applications from plumbing pipes to window frames, insulation, lining, building textiles and packaging.
- A shift towards improved methods of plastics recycling, complemented by novel bio-based and biodegradable plastics wherever possible, requires major support for advances in plastics production and recycling.



IMPROVE

- Options for decarbonising glass production include switching the energy source, electrification of all processes, process intensification and waste heat recovery.
- In renovation and deconstruction, off-site window disassembly avoids contamination and allows for glass recycling.



IMPROVE

- High quality earth-based masonry has potential to replace concrete in many low-rise applications but needs development and regulation.
- Diverse earth masonry materials made from clay-rich soil and natural fibres, that are dried in the sun or fired, have been used for much of human history and are often re-used.
- Increasingly masonry bricks have adopted the use of high carbon cement binders and high temperature firing to address mechanical and moisture performance.
- If locally made with low-carbon binders, additives and processing methods, earth masonry can regain its role as a viable building material.



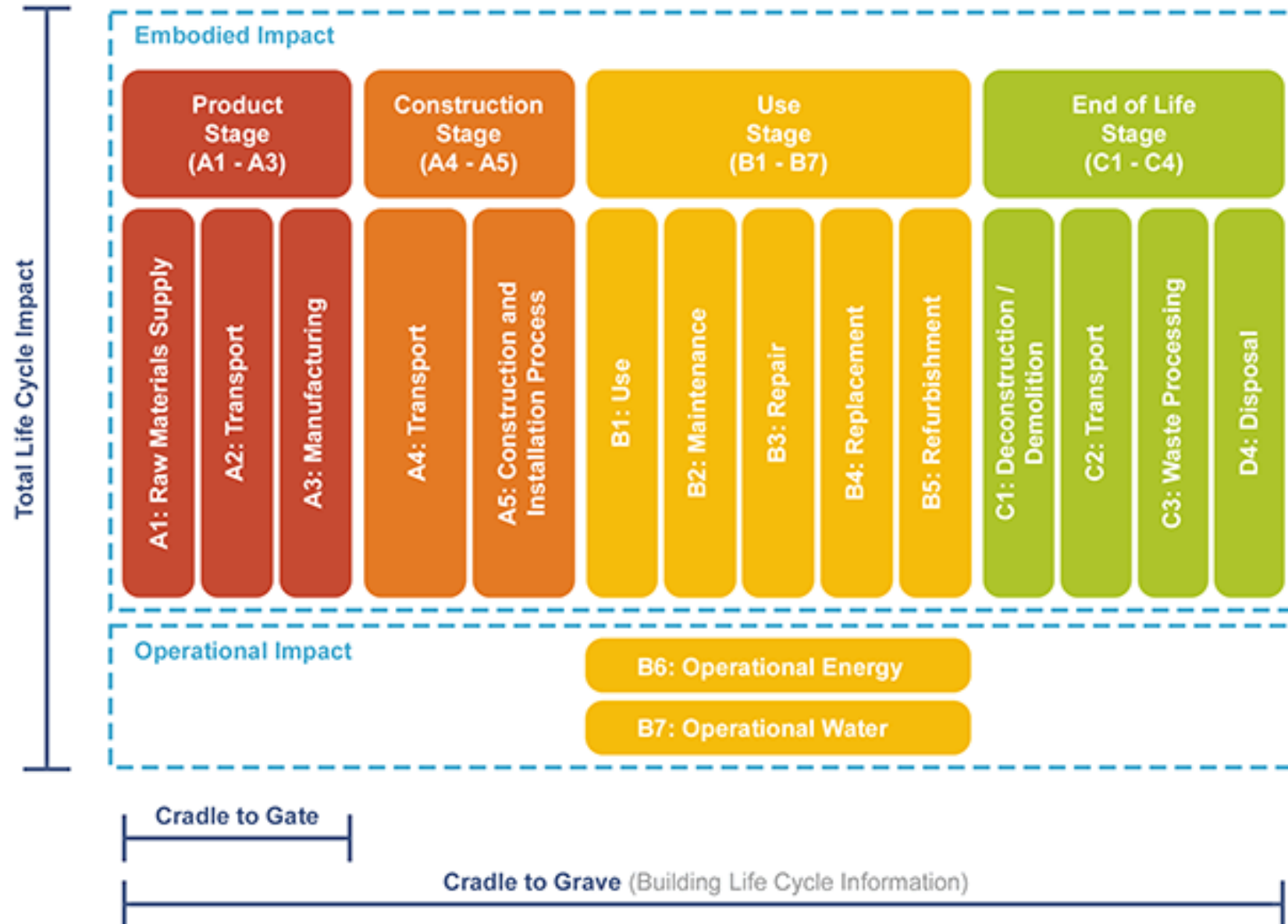
EMBODIED CARBON CALCULATIONS

- Allows a direct comparison between different materials to choose those with lower carbon footprints.
- Highlights high emission materials, guiding designers towards more sustainable alternatives.
- The most important time to calculate embodied carbon is in the early design stages.

EMBODIED CARBON CALCULATIONS

- The unit used to measure the total greenhouse gas (GHG) emissions of a particular activity, product or process in terms of the amount of CO₂ that would have the same global warming potential is called kilograms of carbon dioxide equivalent (kgCO₂e).

LIFE CYCLE MODULES



MINIMUM SCOPE AND FOCUS ON A1–A5 STAGES

Scope of A1–A5 Stages

A1 to A5 stages cover cradle to practical completion, forming the minimum scope for embodied carbon calculations.

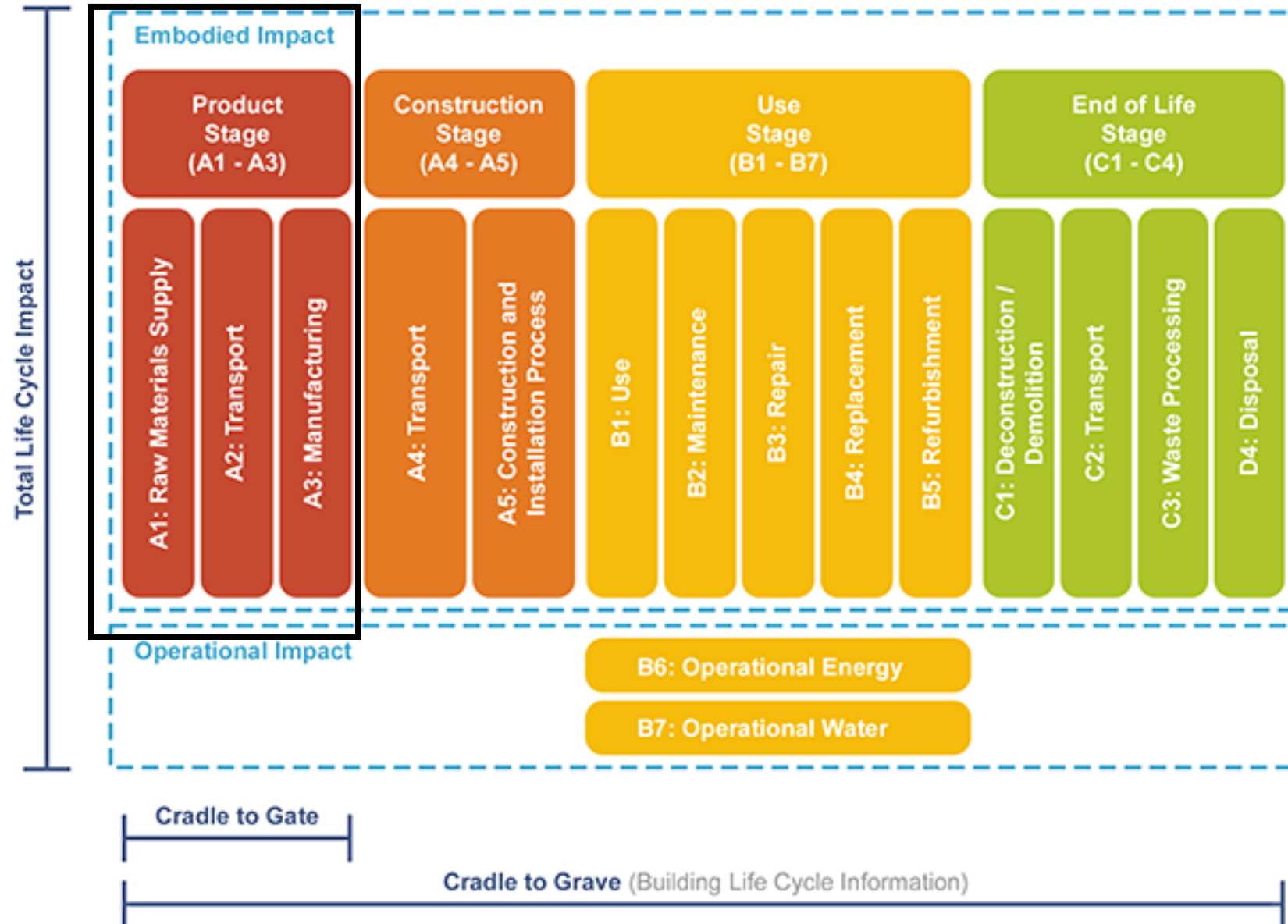
Focus on Production and Construction

The article focuses on carbon calculation for structural materials during production (A1–A3) and construction (A4–A5) stages.

Importance of Addressing Embodied Carbon

Addressing embodied carbon in these stages is urgent to respond effectively to the climate emergency.

LIFE CYCLE MODULES



EMBODIED CARBON CALCULATIONS

The fundamental principle of an embodied carbon calculation is to multiply the quantity of each material by a carbon factor for the life cycle modules being considered:

$$\text{material quantity (kg)} \times \text{carbon factor (kgCO}_2\text{e/kg)} = \text{embodied carbon (kgCO}_2\text{e)}$$

TABLE 2: A1–A3 ECFs for typical structural materials

Material	Type	Specification/details	A1–A3 ECF (kgCO ₂ e/kg)	Data source
Concrete	<i>In situ</i> : piling, substructure, superstructure	Unreinforced, C30/37, UK average ready-mixed concrete EPD[1] (35% cement replacement)	0.103	MPA, 2018[2]
		Unreinforced, C32/40, 25% GGBS cement replacement[3]	0.120	ICE V3[4]
		Unreinforced, C32/40, 50% GGBS cement replacement	0.089	ICE V3
		Unreinforced, C32/40, 75% GGBS cement replacement	0.063	ICE V3
		Unreinforced, C40/50, 25% GGBS cement replacement	0.138	ICE V3
		Unreinforced, C40/50, 50% GGBS cement replacement	0.102	ICE V3
		Unreinforced, C40/50, 75% GGBS cement replacement	0.072	ICE V3
	Precast	Unreinforced, C40/50 with average UK cement mix	0.178	ICE V3
		Reinforced, 150mm prestressed hollow core slab: British Precast Concrete Federation average EPD	50.2kgCO ₂ e/m ²	BPCF, 2017[5]
Steel	Reinforcement bars	UK: BRC EPD	0.684	BRC, 2019[6]
		Worldwide: Worldsteel LCI study data, 2018, world average	1.99	ICE V3
	PT strands	Assume the same as reinforcement bars		
	Structural sections	UK open sections: British Steel EPD	2.45	BS, 2020[7]
		Europe (excl. UK): Bauforumstahl[8] average EPD	1.13	Bauforumstahl, 2018
		Worldwide: Worldsteel LCI study data, 2018, world average	1.55	ICE V3
	Galvanised profiled sheet (for decking)	UK: TATA Comflor EPD	2.74	TATA, 2018
Blockwork	Precast concrete blocks	Lightweight blocks	0.28	ICE V3
Brick	Single engineering clay brick	Generic, UK	0.213	ICE V3
Timber, excl. carbon sequestration[9], [10]	Manufactured structural timber	CLT, 100% FSC/PEFC	0.437	ICE V3
		Glulam, 100% FSC/PEFC	0.512	ICE V3
	Studwork/framing/flooring	Softwood, 100% FSC/PEFC	0.263	ICE V3
	Formwork	Plywood, 100% FSC/PEFC	0.681	ICE V3
Plasterboard	Partitioning/ceilings	Minimum 60% recycled content	0.39	ICE V2
Intumescent paint	For steelwork	Specific EPD: Amotherm steel WB, Amonn	2.31	AMONN, 2019[11]

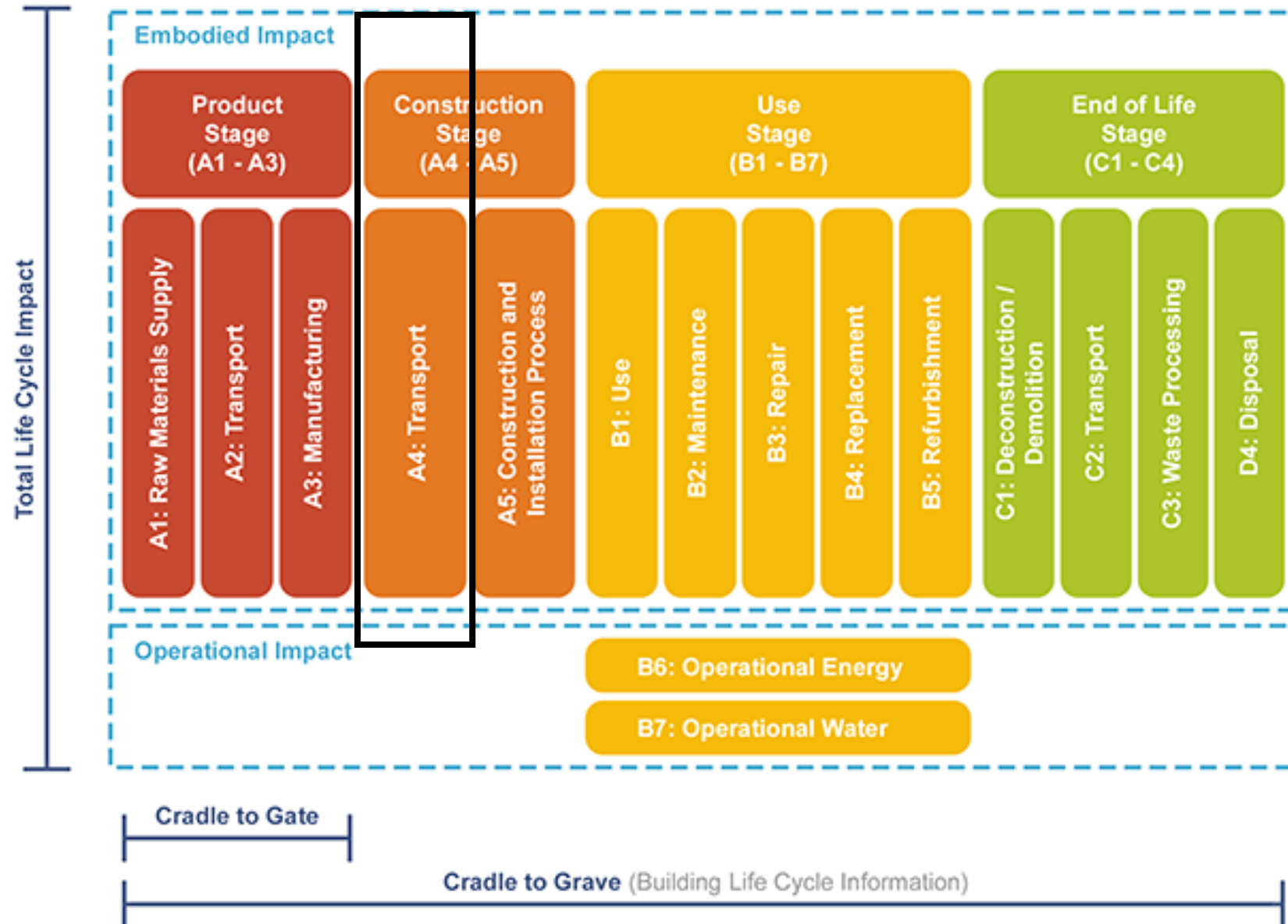
Data taken from CEC Table 2, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation.

MATERIAL QUANTITIES

- The first step is to determine the quantities of materials used in the project.
- This can be done through manual calculations, BIM, structural analysis models, bill of quantities

0 Facilitating works	0.1 Hazardous materials treatment and removal
	0.2 Demolition works
	0.3 Temporary/enabling works
	0.4 Specialist groundworks
1 Substructure	1.1 Foundations incl. excavations
	1.2 Basement retaining walls
	1.3 Lowest floor slab
2 Superstructure	2.1 Frame
	2.2 Upper floors incl. balconies
	2.3 Roof
	2.4 Stairs and ramps
3 Internal finishes	3.1 Wall finishes incl. internal partitioning
	3.2 Floor finishes
	3.3 Ceiling finishes
4 Fittings, furnishings and equipment	4.1 Building-related*
	4.2 Non building-related**
5 Services/MEP	5.1 Building-related* – HVAC incl. sanitary
	5.2 Building-related* – lighting
	5.3 Building-related* – lifts and escalators
	5.4 Building-related* – safety, security and communication installations
	5.5 Non building-related**
6 Facade	6.1 External walls/opaque cladding
	6.2 Curtain walling, windows and external doors
7 External works	7.1 Roads, paths & pavings/hard landscaping
	7.2 Soft landscaping
	7.3 Fencing, railings and walls
	7.4 External fixtures
	7.5 External services incl. drainage

LIFE CYCLE MODULES



EMBODIED CARBON CALCULATIONS

This is a question of identifying the transport types and the associated attributable emissions for delivery to site:

material/system mass x transport distance x carbon factor (kgCO₂e/kg)

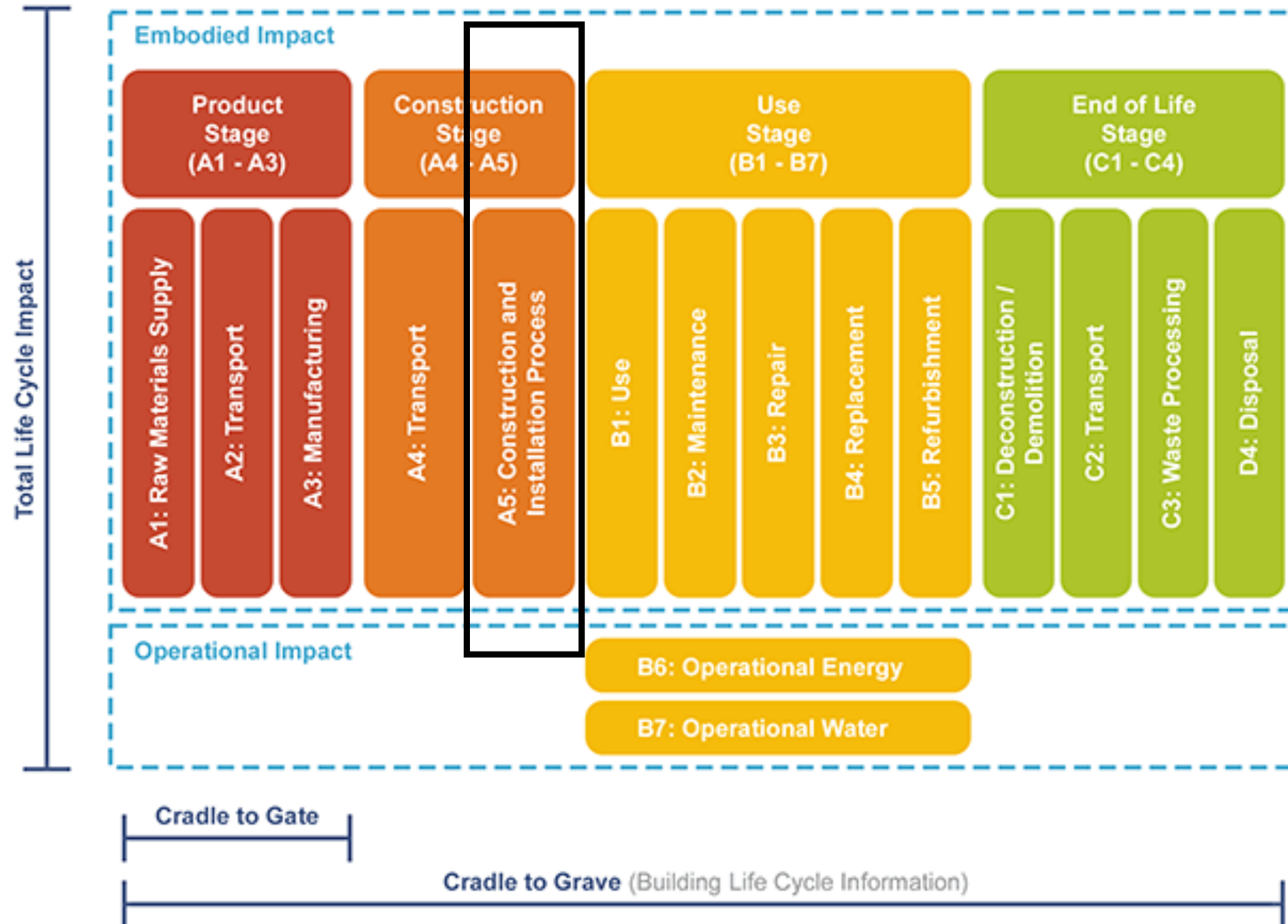
TABLE 3: Transport emissions factors for different modes of transport

Mode	TEF _{mode} (gCO ₂ e/kg/km)	Source
Road transport emissions	0.10650	(BEIS, 2020)[1]
Sea transport emissions	0.01614	(BEIS, 2020)[2]
Freight flight emissions	0.59943	(BEIS, 2020)[3]
Rail transport emissions	0.02556	(BEIS, 2020)[4]
Data taken from CEC Table 4, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation. [1] For HGV (all diesel), all HGVs, average laden. [2] For cargo ship, container ship, average. [3] International, to/from non-UK, without RF. [4] Freight train. BEIS, 2020. <i>Greenhouse gas reporting: conversion factors 2020</i>. London, BEIS. Available online at https://carbon.tips/cf2020 (last accessed 23/02/20)		

TABLE 4: A4 ECFs for typical transport scenarios (UK)

A4 Transport scenario	km travelled by road	A4 ECF (kgCO ₂ e/kg)
Locally manufactured	50	0.005
Nationally manufactured	300	0.032
European manufactured	1500	0.160
Data taken from CEC Table 5, and correct at time of publication. Check data sources to verify that data presented here are valid at time of your calculation.		

LIFE CYCLE MODULES



EMBODIED CARBON CALCULATIONS

- The carbon emissions from all onsite activities and plant accommodation should be covered.
- The average figure for construction site emissions of 1400kgCO₂e/£100k of project value.

EMBODIED CARBON CALCULATIONS

- Appropriate allowances for site waste should be made. The site waste rates for different materials should be determined based on the standard wastage rates provided by

TABLE 5: Waste factors for typical structural materials)

Material/product	Waste rate (WR)	Waste factor (WF)[1]	WRAP Net Waste Tool reference
Concrete <i>in situ</i>	5%	0.053	Table 2, concrete <i>in situ</i>
Concrete precast (beams and frames)	1%	0.010	Table 2, concrete precast (large precast elements)
Steel reinforcement	5%	0.053	Appendix 1, frame: <i>in situ</i> concrete frame generic; Table 2, ferrous metals
Steel frame	1%	0.010	Appendix 1, frame: steel frame generic
Blockwork	20%	0.250	Table 2, bricks & blocks
Brick	20%	0.250	Table 2, bricks & blocks
Timber frames (beams, columns, braces)	1%	0.010	Appendix 1, frame: timber frame
Timber floors (joists, boards)	10%	0.111	Appendix 1, floor: wooden floor
Plasterboard	22.5%	0.290	Table 2, plasterboard; Table 3: boarding
Sprayed cementitious fire protection	10%	0.111	Table 3: cementitious sprays