IRF India Chapter, 19th June 2024

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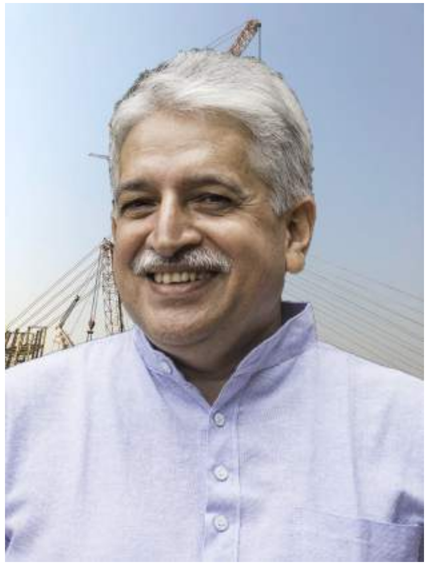
Design Engineering Construction
DECon Complete Solutions

Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction

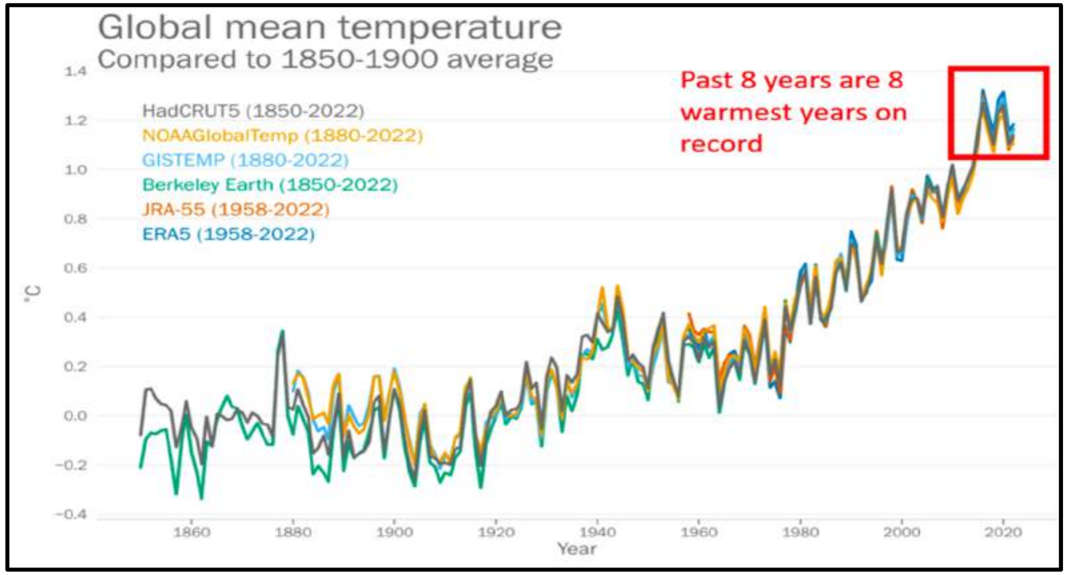
V N Heggade
Founder & CEO of DECon Complete Solutions



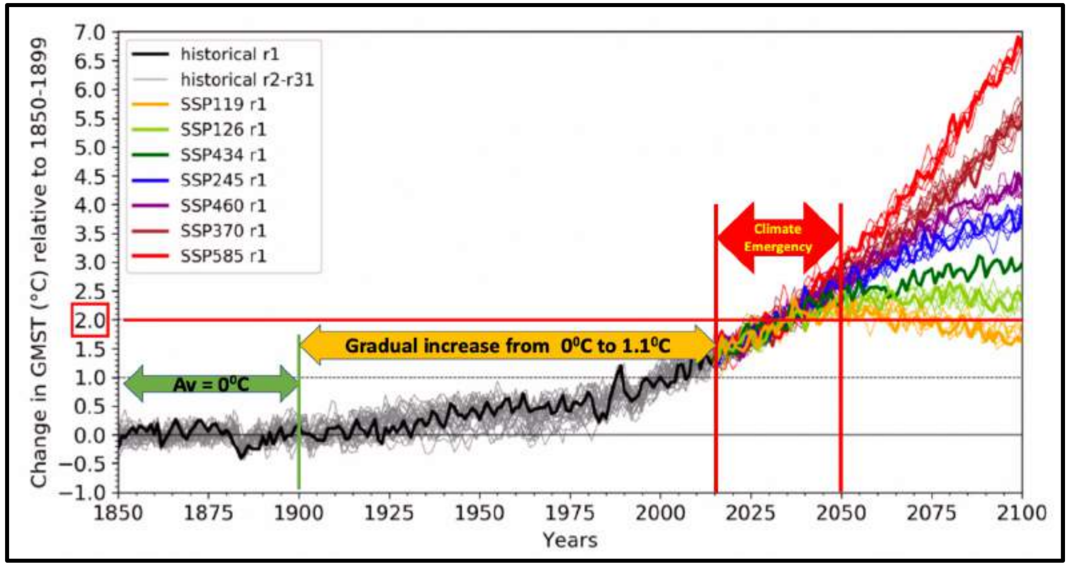
V.N. Heggade, Former Chief Executive Officer (CEO) of STUP Consultants & former Executive Director of Gammon is a senior professional with a rich experience of nearly four decades in Construction sector in the areas of Design Management, Technical Management, Site Management, Project Management & Contract Management of Highways, Bridges, Energy structures like Chimneys & Cooling towers, Environmental, Marine and Hydraulic structures.

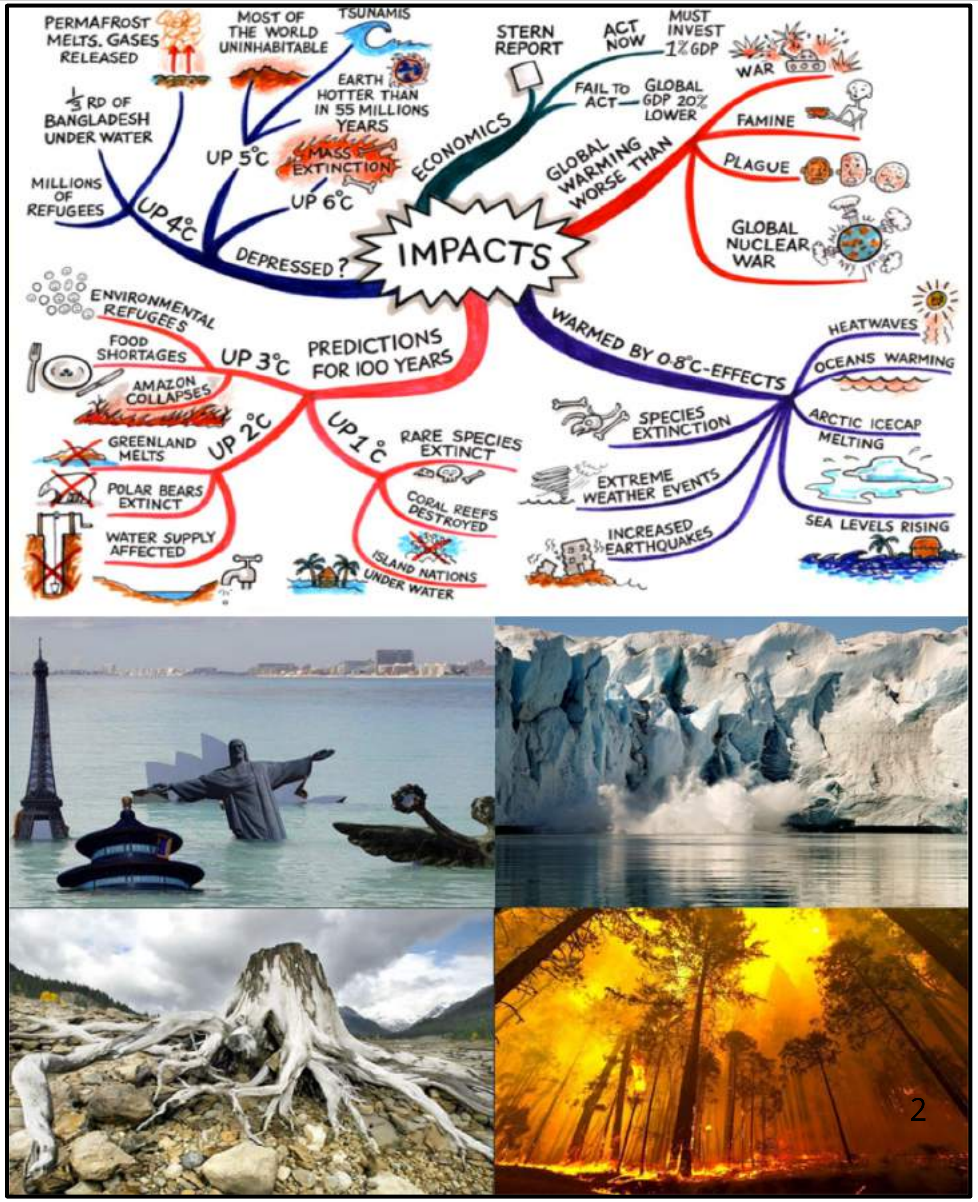
He is a recipient of around 16 National recognitions in addition to an International prize & fellowship from IABSE & fib Zurich. He has more than 200 publications including papers in journals, conference proceedings & chapters in guidelines to his credit and is a member of various IRC (Indian Roads Congress) and BIS (Bureau Of Indian Standards) committees. He is also a member of TG 10.1 of Federation Internationale Du Beton, which is a special Task Group working on FIB Model code 2020. ***Presently, he is a convener of sub committee IRC B-5.3 to bring out a special guidelines on carbon neutrality for steel bridges. Recently he is conferred with the fellowship of 'fib'. He is also a Fellow of Indian National Academy of Engineering (FNAE).***

Global temperatures rise & consequent climate emergency



Source : WMO Global Annual to Decadal Climate Update, 17th May 2023.





World CO_2 emissions data (2020)

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CO_2 emissions world wide. ($ktCO_{2eq}$)

Region	$ktCO_{2eq}$	%age
World	3,43,44,006.07	100.00
China	1,07,07,219.73	31.18
US	48,17,720.21	14.03
India	24,56,300.05	7.15
Russia	17,03,589.97	4.96
Japan	10,81,569.95	3.15
Germany	6,57,400.02	1.91
Iran	6,30,010.01	1.83
Indonesia	6,19,840.03	1.80
Korea	6,10,789.98	1.78
Canada	5,80,210.02	1.69
Saudi Arabia	5,23,780.03	1.53
Mexico	4,49,269.99	1.31
South Africa	4,39,640.01	1.28
Brazil	4,34,299.99	1.26
Turkiye	3,96,840.00	1.16
Australia	3,86,530.00	1.13
UK	3,48,920.01	1.02
Vietnam	3,36,489.99	0.98
Italy	3,17,239.99	0.92
France	3,00,519.99	0.88
Others	60,83,770.30	17.71

GHG emissions world wide

Region	$ktCO_{2eq}$	%age
World	4,62,87,620.03	100.00
China	1,27,05,089.84	27.45
US	60,01,209.96	12.97
India	33,94,870.12	7.33
Russia	24,76,840.09	5.35
Japan	11,66,510.01	2.52
Brazil	10,57,260.01	2.28
Indonesia	10,02,370.00	2.17
Iran	8,93,719.97	1.93
Germany	7,49,710.02	1.62
Canada	7,36,929.99	1.59
Saudi Arabia	7,23,150.02	1.56
Korea, Rep.	6,98,460.02	1.51
Mexico	6,53,870.00	1.41
Australia	5,85,979.98	1.27
South Africa	5,55,429.99	1.20
Turkiye	4,88,470.00	1.06
Vietnam	4,50,149.99	0.97
UK	4,40,079.99	0.95
Pakistan	4,32,500.00	0.93
Thailand	4,22,090.00	0.91
France	4,14,040.01	0.89
Italy	3,89,000.00	0.84
Others	98,49,820.20	21.28

Source :Climate Watch. 2020. GHG Emissions. Washington, DC: World Resources Institute. Available at: https://www.climatewatchdata.org/ghg-emissions.

- Total greenhouse gas emissions in kt of CO_2 equivalent are composed of CO_2 totals **excluding short-cycle biomass burning** (such as agricultural waste burning and savanna burning) but including other biomass burning (such as forest fires, post-burn decay, peat fires and decay of drained peatlands), **all anthropogenic CH_4 sources, N_2O sources and F-gases** (HFCs, PFCs and SF6).
- Carbon dioxide (CO_2) emissions are those stemming from the **burning of fossil fuels and the manufacture of materials. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.**
  - ✓ **1 Gt = 10,00,000 Kt.**
  - ✓ **1 Gt = 1000 Million t.**

World & Sector wise CO_2 emissions (2022)

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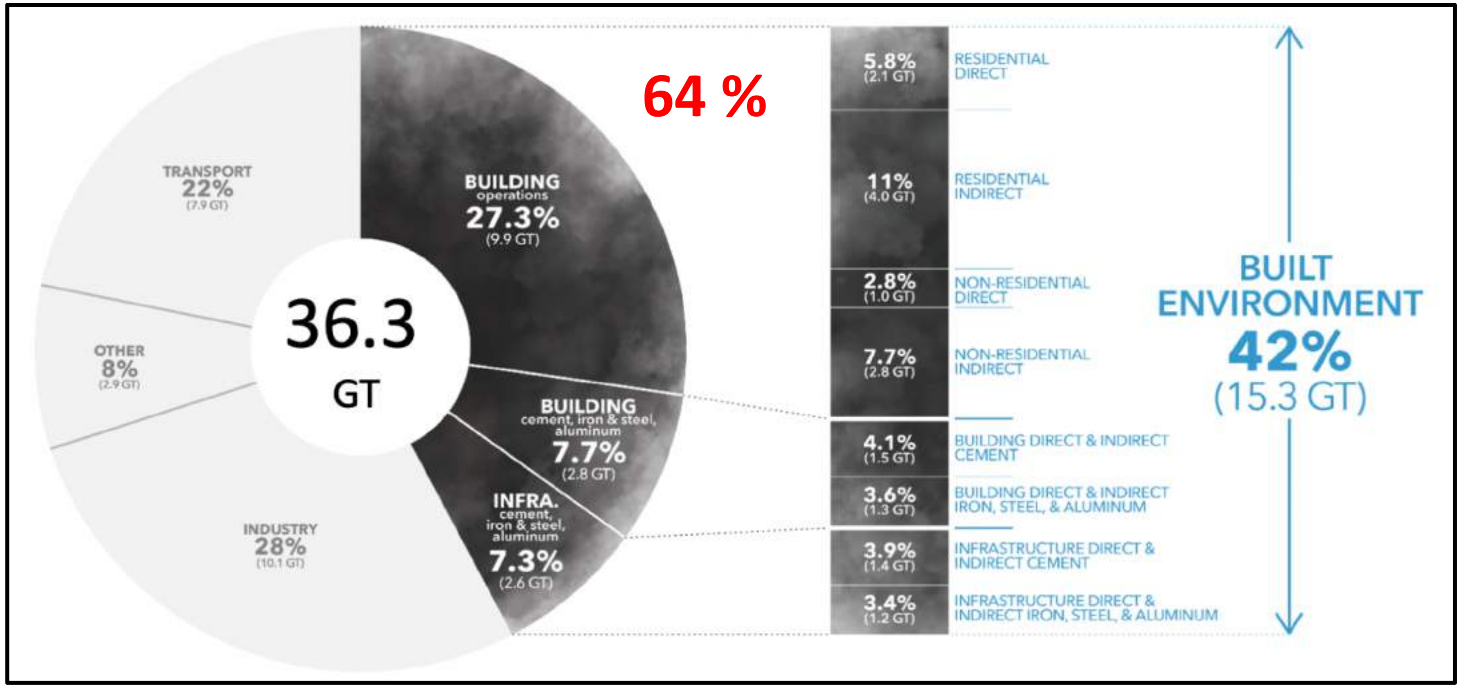
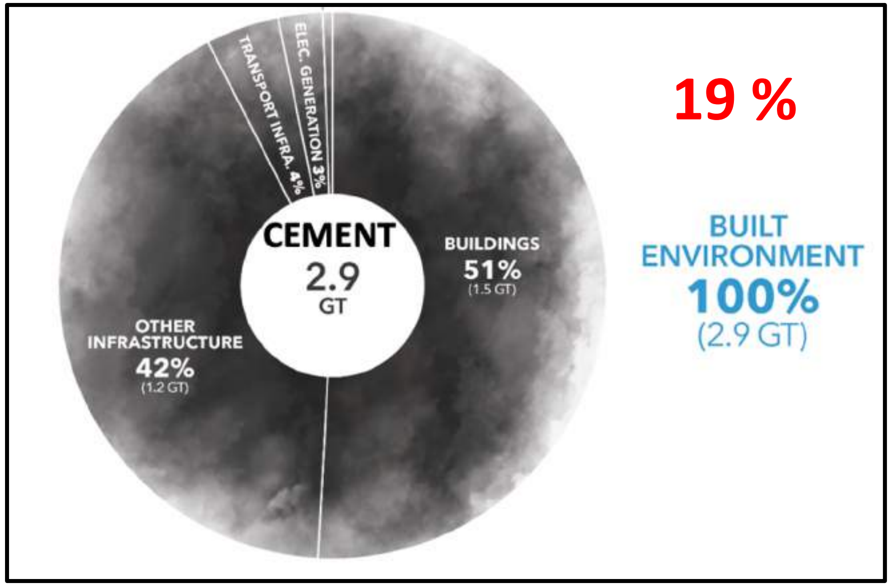
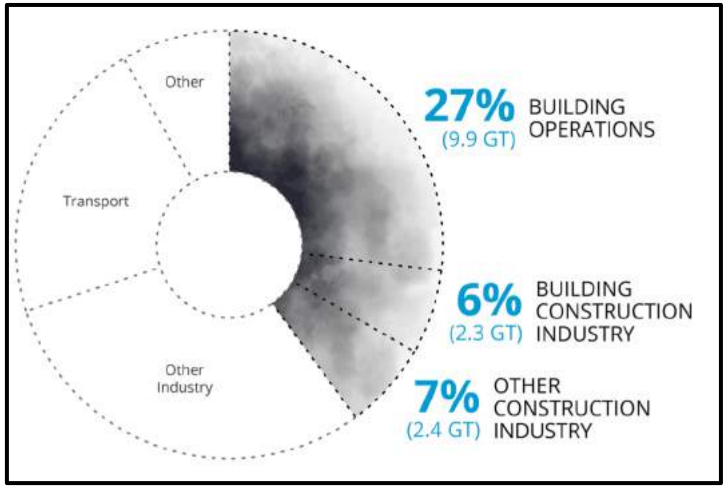
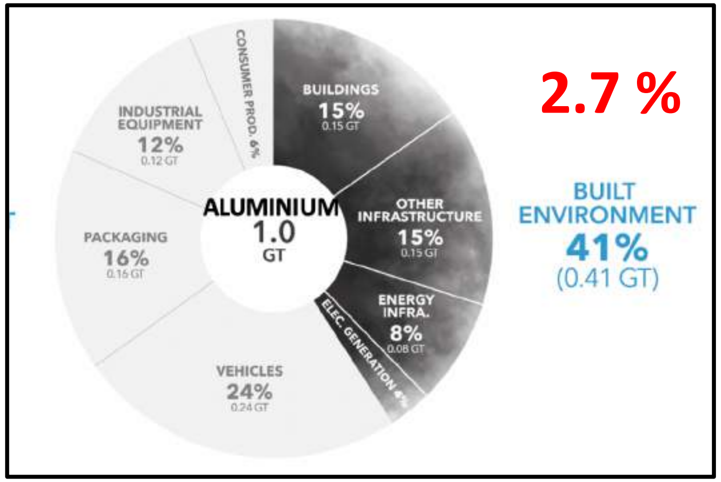
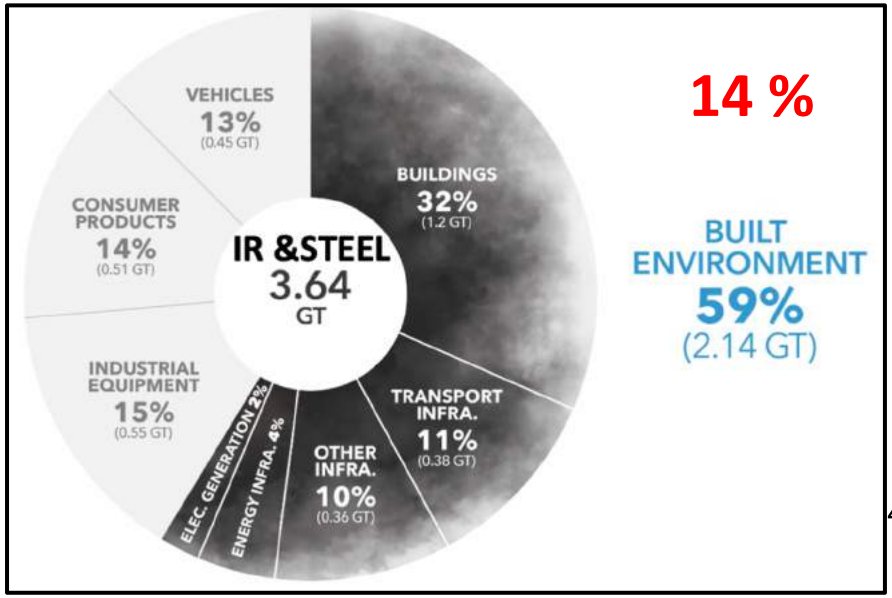






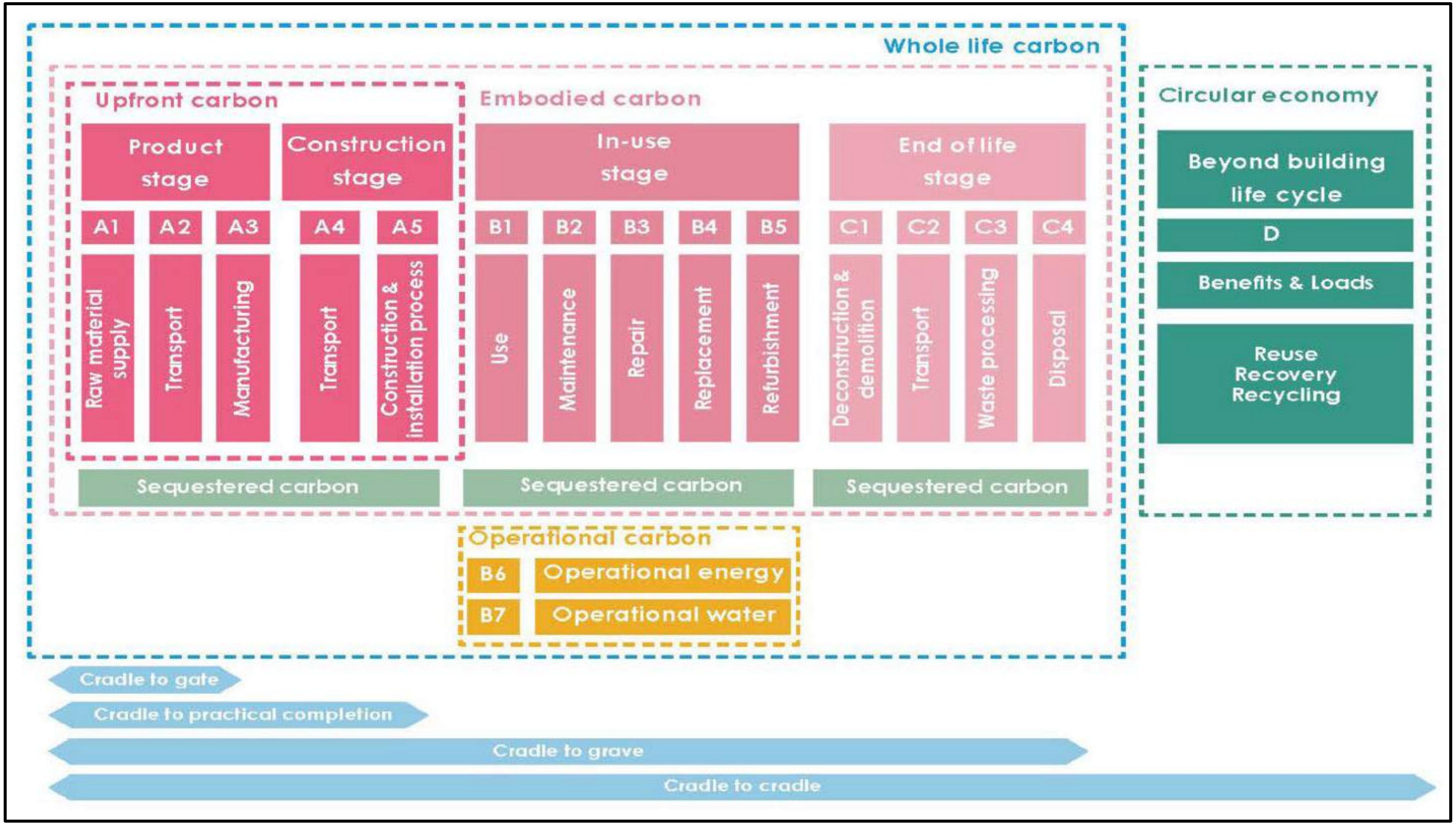




CO_2 in the Built-Environment

- **Capital Carbon** is the carbon associated with the assets. It consists of
  - ✓Embodied Carbon at Product stage,
  - ✓Emissions during transportation & construction,
  - ✓Emissions because of Maintenance, refurbishment, strengthening during service life
  - ✓Emissions during demolition, dismantling, landfilling or recycling after the service life
- **Operational Carbon** encompasses emissions that arise owing to the *energy-centric operations in buildings & infrastructure.*
  - ✓*Heating, cooling ,ventilation and lighting (HVAC)*.
  - ✓Lifts, water pumps, common lighting
  - ✓Household appliances such as fridges, washing machines, TVs, computers, and cooking applications, etc.
- **User Carbon** is the emissions during the usage of assets
  - ✓For example when the bridge asset is used by the transportation vehicles, the carbon emissions by the vehicles

Life cycle stages defined by BS EN 15978:2011

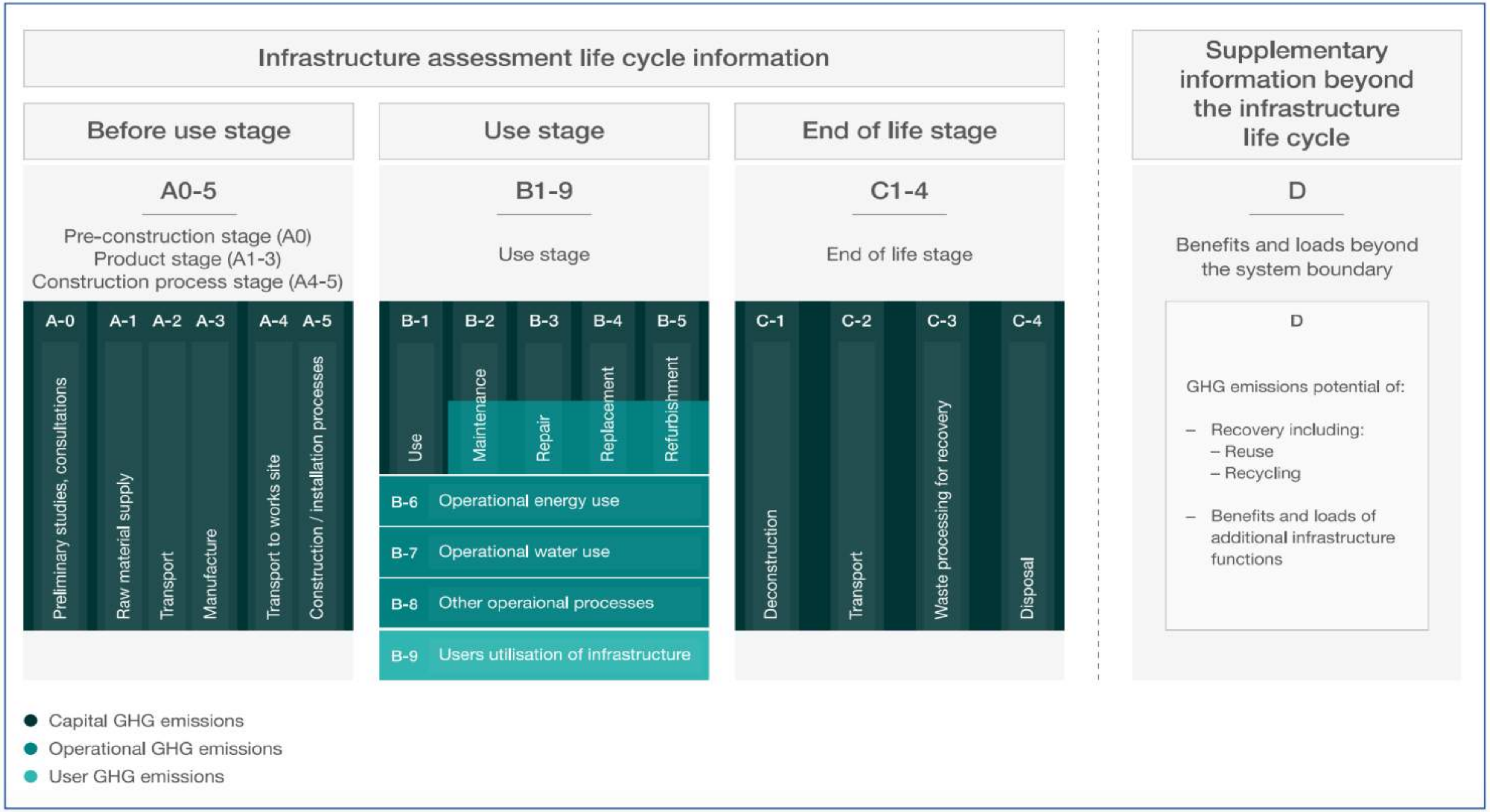


Source : LETI (2020). Embodied Carbon Primer. Available at: https://carbon.tips/leti

Modules	Buildings
A1-A3	50%
A4	4%
A5	1%
B1-B5	20%
B6	23%
C1-C4	2%

Source: The Institution of Structural Engineers How to calculate embodied carbon

Modular approach showing the life cycle stages and individual modules for infrastructure carbon emissions quantification



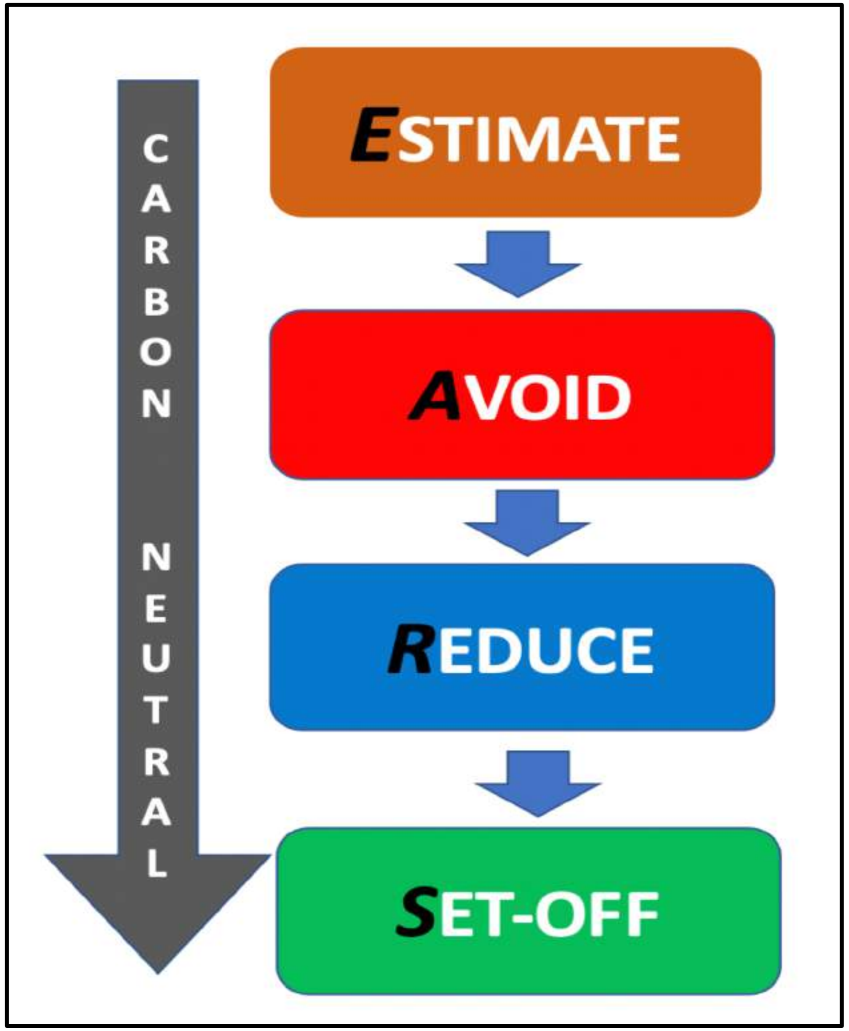
Modules	Infrastructure (%)
A0-A3	40 -50
A4	4-8
A5	
B1-B5	38-60
B6-B9	
C1-C4	1-2

Source: Author's estimation

Source: PAS 2080:2016. Carbon management in infrastructure. London: BSI, 2016

How do we achieve Carbon neutrality ?

- **Carbon neutrality** is a process where GHG emissions are brought to net zero by **avoiding, reducing and setting off** those emissions which **can not be avoided and reduced**.
- This has to be achieved by **DISRUPTING** the otherwise **"Business as usual"** approach.



EARS model by the author

Estimation of Carbon foot print

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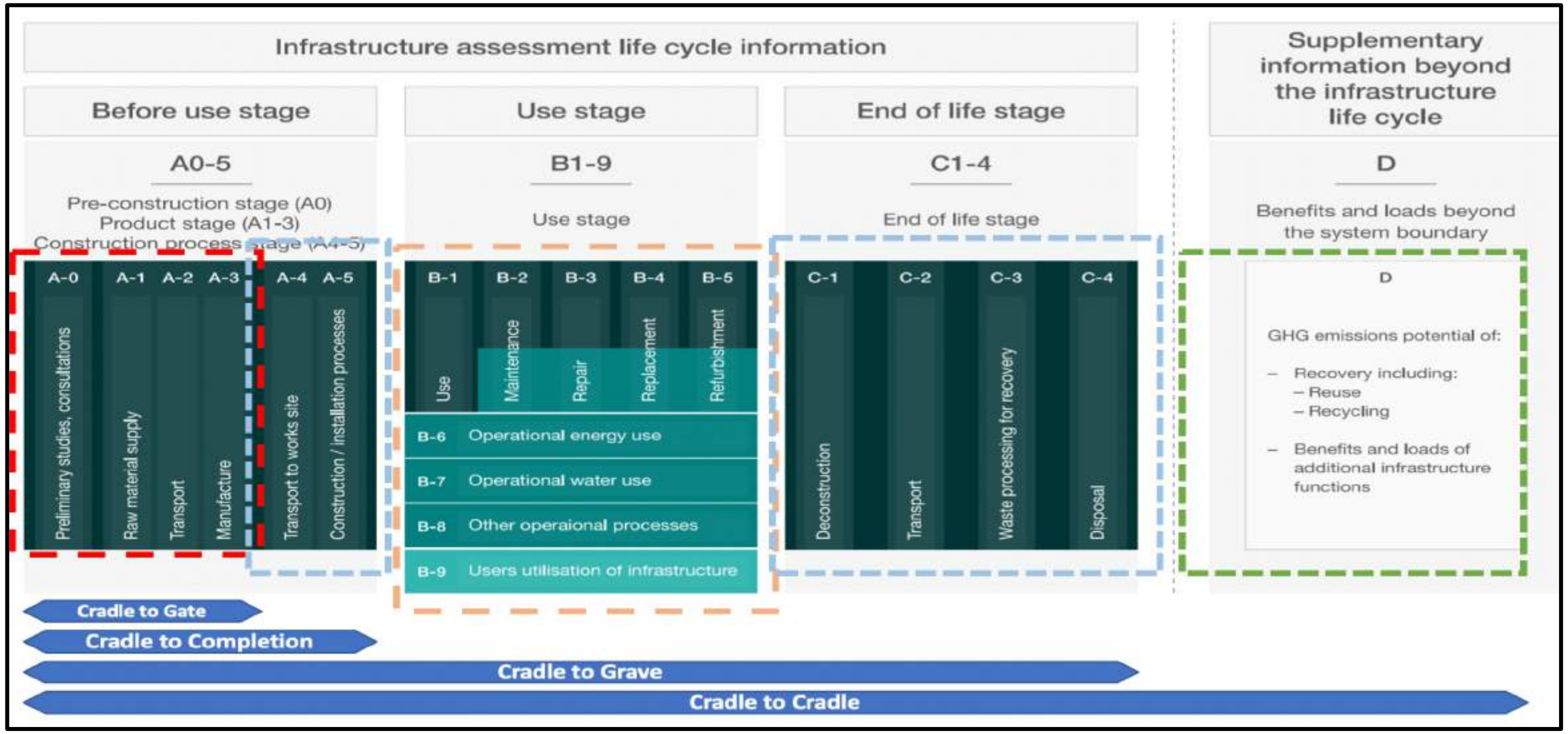

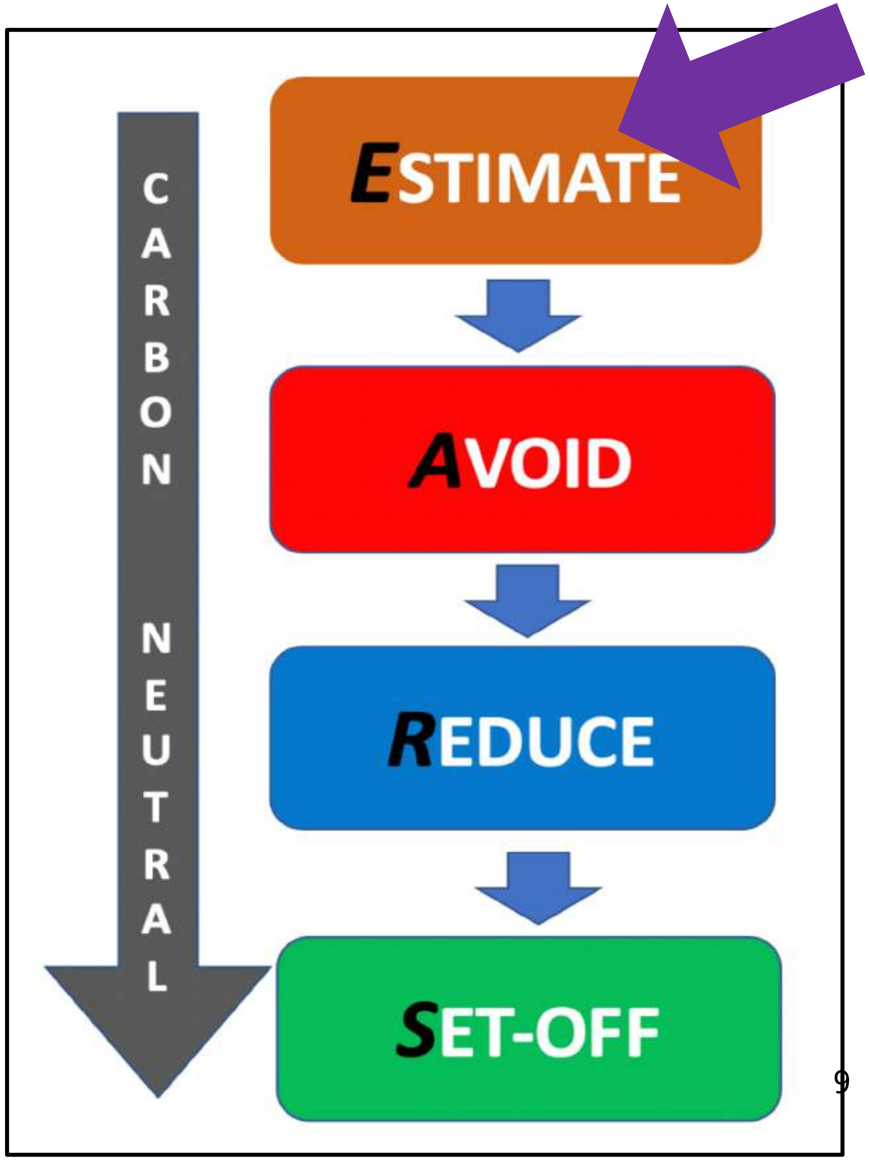

- **Methodologies** of estimation
  - ✓ **Cradle to Gate** estimation (A1-A3)
  - ✓ **Gate to Completion** estimation (A4-A5)
  - ✓ **Completion to End of Life** estimation (In use stage estimation) (B1-B9)
  - ✓ **End of life to Cradle** estimation (Circularity) (C1-C4 & D)

Carbon creation during various stages of life cycle

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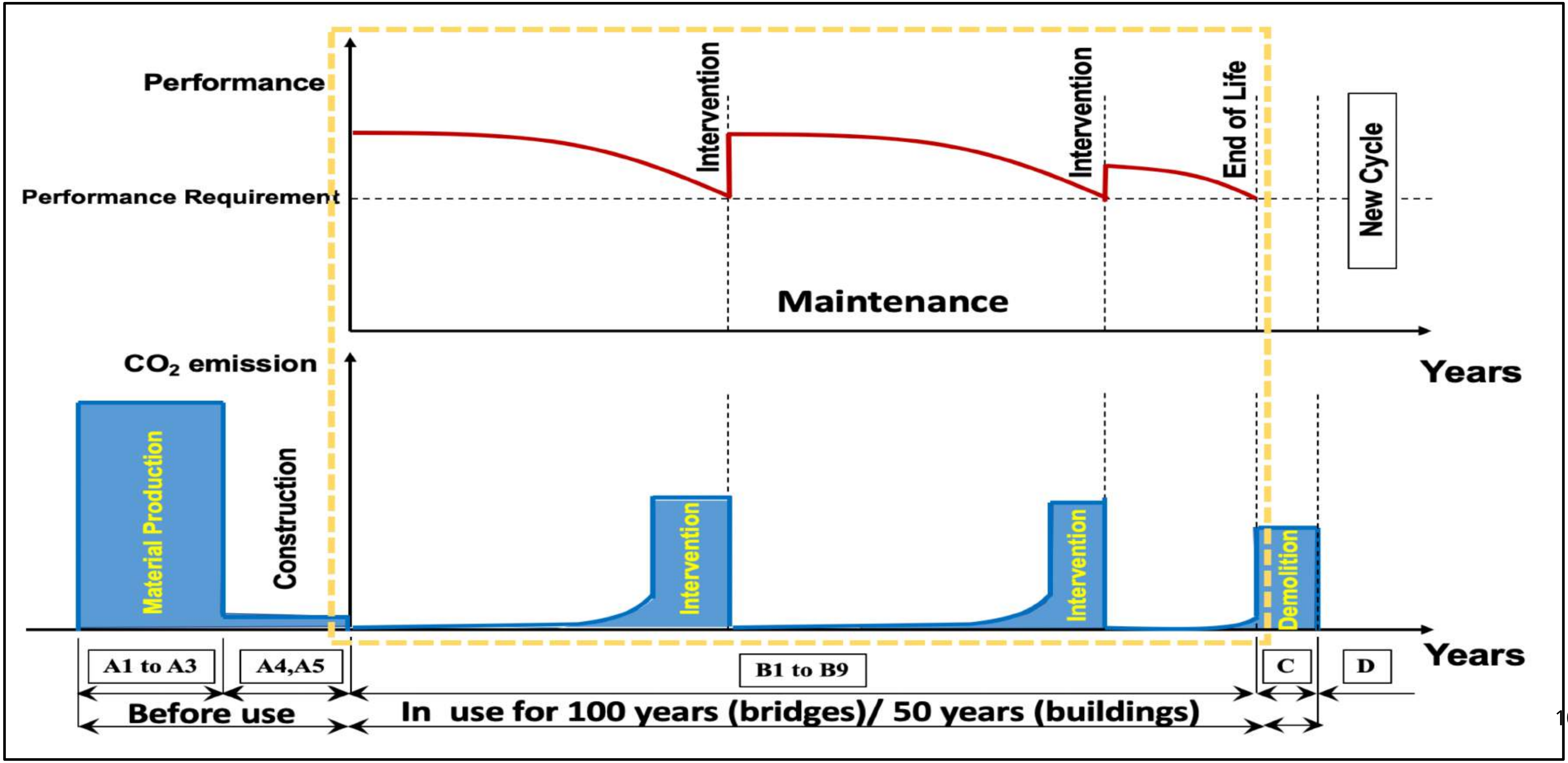

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CF/Unit for the system boundary Cradle to Gate (A1-A3)

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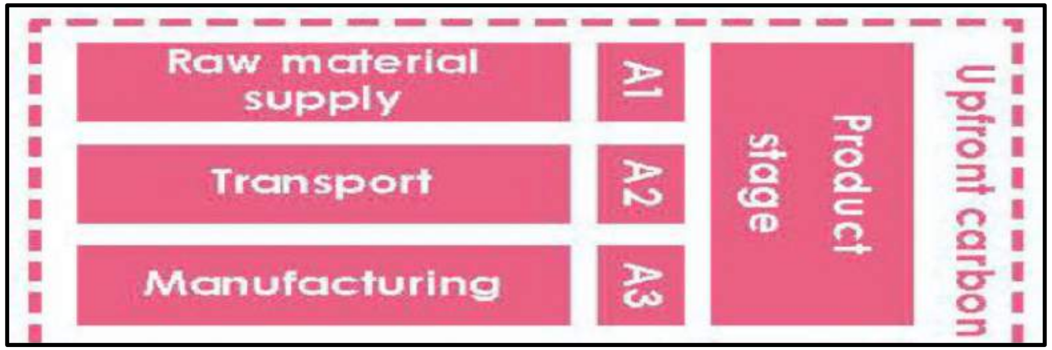
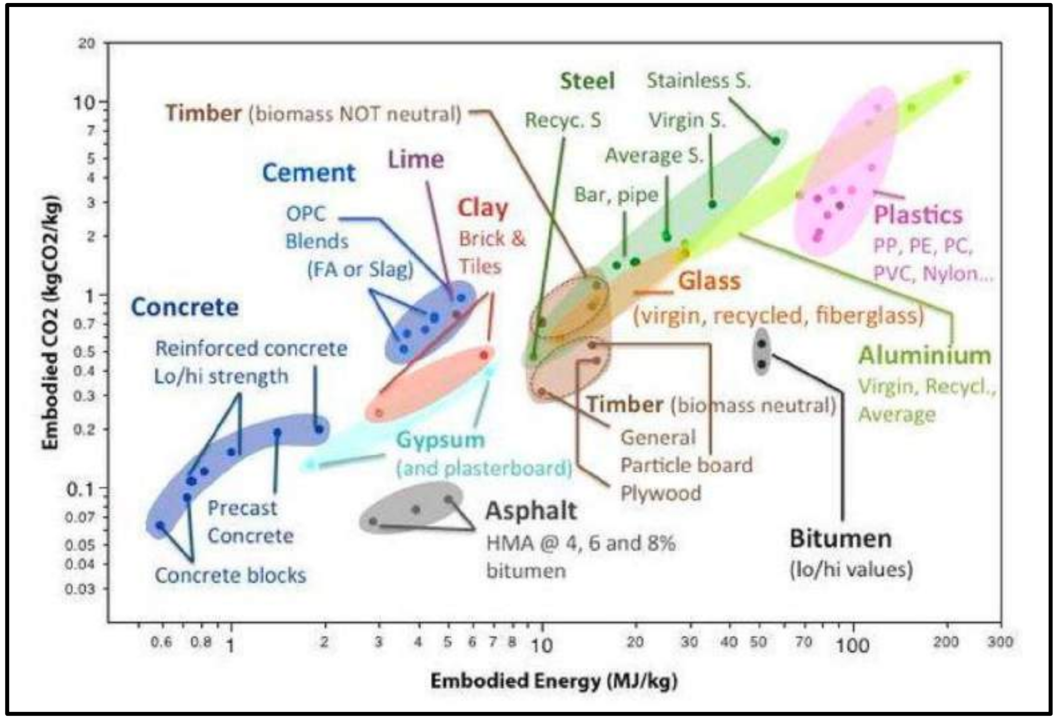
- Embodied carbon comes from the direct emission during the process or production and also the the consumption of energy during the process or production of product.
- Embodied Carbon Factor (ECF) is the direct global warming potential per unit of material, say $kgCO_2/kg$, tCO_2/t, etc.
- Embodied Carbon ($kgCO_2$) = Material quantity (kg) x Embodied Carbon Factor ($kgCO_2/kg$).

Materials/Products	EC (A1-A3) ($t\ CO_2/t$)
M28/M35 Concrete	0.131
M28/M35 Concrete 30% fly ash	0.121
M28/M35 Concrete 50% GGBS	0.076
M28/M35 cement less/geopolymer Concrete	0.04
M32/M40 Concrete	0.153
M 32/M40 Concrete 30% fly ash	0.128
M32/M40 Concrete 50% GGBS	0.094
M32/M40 cement less/geopolymer Concrete	0.046
M40/M50 Concrete	0.176
M40/M50 Concrete 30% fly ash	0.146
M40/M50 Concrete 50% GGBS	0.108
M40/M50 cement less/geopolymer Concrete	0.053
Mortar/Screed	0.150
Aluminum (Primary)	11.49
Aluminum (Recycled)	1.69
Asphalt (4% Bitumen)	0.059
Bitumen	0.49
Quarried Aggregate	0.0052
Sand	0.0051
Soil	0.0240
Stone	0.0790
General plastic	3.310
HDPE pipe	2.52
Reinforcement	(2.60+0.01*)
Structural steel	(2.5+0.3*)
Prestressing steel	(2.1+0.1*)
Steel (General)	2.890
Steel (Recycled)	0.470
Natural gas liquids	2.8381
Glass	1.50
Brick	0.213
Epoxide resin	5.70
Stainless steel (recycled)	3.8
Stainless steel (Primary)	6.0
Wood	0.5

Materials/Products	EC (A1-A3) ($t\ CO_2/t$)
Bearings	**($t\ CO_2/no$)**
Steel rocker/roller	2.0 (<400t)
Elastomeric	0.2(<100t)
	0.8(100-200t)
Spherical	1.21(<100t)
	5.63(100-200t)
	10.26(200-300t)
	15.75 (300-400t)
	21.57(400-500t)
Pot	0.97(<100t)
	5.09(100-200t)
	9.29(200-300t)
	14.28(300-400t)
	18.07(400-500t)
Expansion joints	**($t\ CO_2/m$)**
All types	0.14 (<99m)
	0.37(100-120m)
	0.61(> 120m)
Fuel	**($Kg\ CO_2/liter$)**
Motor Gasoline	2.2721
Other Kerosene	2.5197
Gas/Diesel Oil	2.6769
Liquified petroleum gases	1.6118
Protective treatments	**($t\ CO_2/m^2$)**
Polymer solvent based-typical	0.0018
Polymer solvent based-marine	0.0041
Hot dip galvanizing-zinc coating	0.0031
Surfacing	**($t\ CO_2/m^2$)**
Water proofing by sheets/sprays	0.012
Water proofing by bitumen	0.005
Combined water proofing and surfacing	0.026
services	**($t\ CO_2/m$)**
PVC pipes < 150mm	0.01
Cast iron pipes < 150mm	0.08
Vitrified clay pipes < 150mm	0.01
Transportation	**($Kg\ CO_2/t\text{-}km$)**
Goods Capacity (8-10t)	0.25
Goods Capacity (10-18t)	0.18
Goods Capacity (18-30t)	0.16





Source : Hammond, G. P. and Jones, C. I. (2008) Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers - Energy, 161 (2). pp. 87-98. ISSN 1751-4223

ECF/Unit for the system boundary Gate to Completion (A4-A5)

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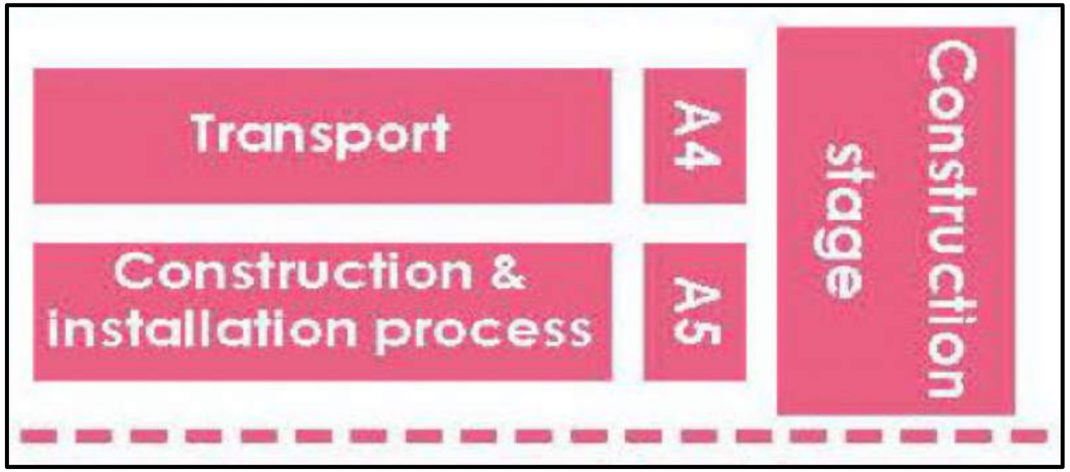
- At the construction stage (A4-A5), the embodied carbon calculations are carried out for the construction and construction process including transportation and handling of the final product.
- During the construction, carbon emission is basically because of :
  - ✓ **Fuel consumption of plant, equipment & vehicles.**
  - ✓ **Wastages in materials**
  - ✓ **Use of enabling & temporary structures**

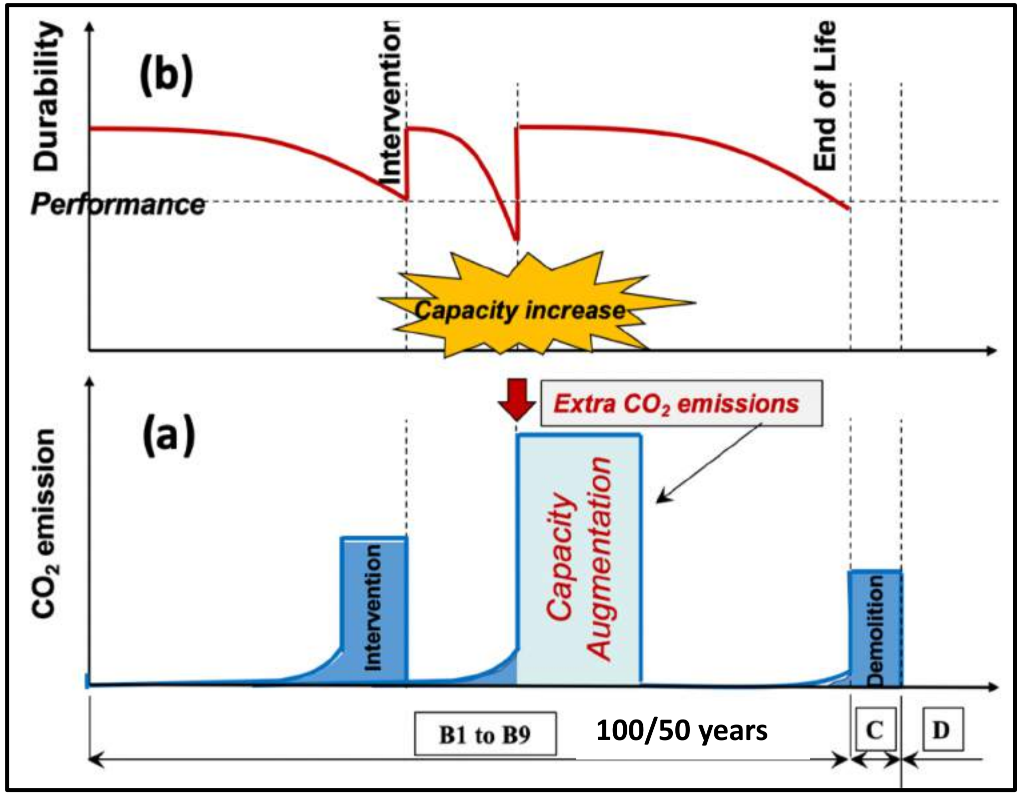
Description (Equipment for A4-A5)	Capacity	Fuel/hr litres
Excavator	EX 210	14
Hydraulic excavator	9 Mt	10
JCB	1.1 cum	6
Tractors	35Hp	2
Hydra Crane	14 Mt	6
B/Plant	60 Cum	24.54
Generator (DG)	>55 Kva	9
Generator(DG)	500 Kva	16
Transit Mixer Truck	6 Cum	12
Transit Mixer Boat	6 Cum	10
Piling Rig	Rotary	16
Bed Gantry	225 Mt	14
Bed Gantry	40 Mt	6
Boom Placer - Floating	90 Cum	10
Boom Placer - Truck	90 Cum	12
Boom placer-BP 350	62 Cum	8
Concrete pump	62 Cum	8
Concrete Pump	45 Cum	6
Diesel Welding Sets	400AMP	4
Crawler crane	80 Mt	12
Crawler Crane	140Mt	14
DD Winch	20 Mt	8
Barges for Crane	200 Mt	12
Tug Boat	156 Hp	9
Power Boats	10 Mt	8
Compressors	600 Cfm	6
lighting tower	5 KVA	1
Haulers		**Fuel/Km In litres**
Dumper/Tipper/Trailer	20 Mt	4
Trucks/Trailer	10t	6
Multi Axle Trailer	200Mt	2

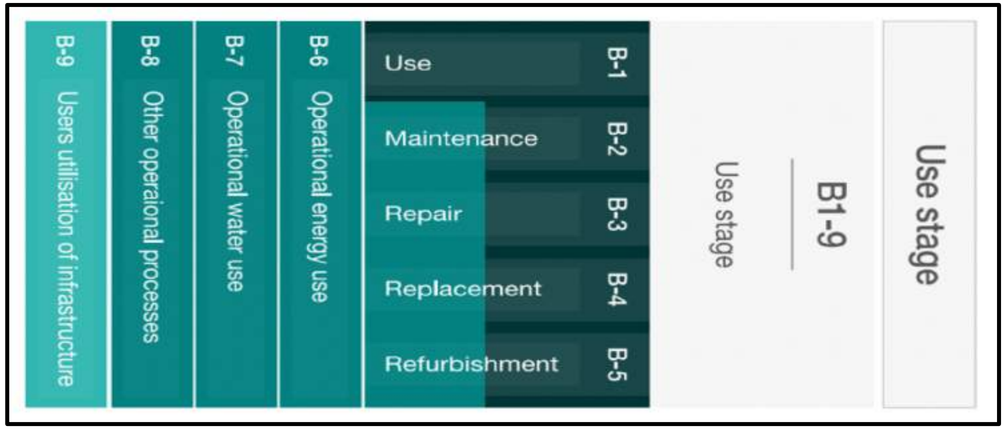


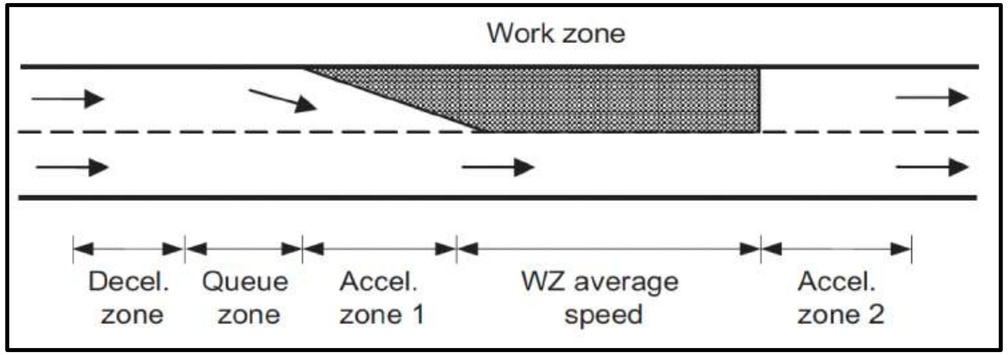
S.No	Product/Material	Wastage (%)
1	Concrete in situ	5
2	Concrete precast	1
3	Structural steel	1
4	Reinforcement Steel	5
5	Glass	5
6	Aluminum	1
7	Mortar/screed	5
8	Timber frames	1
9	Timber enabling	10
10	Stone	10
11	Brick	20

Carbon calculations for 'In use' stage (B1-B9)

- Stages B1 through B9 have very little data.
- Capital carbon due to maintenance, repairs, rehabilitation.
- Operational Carbon due to energy centric operations.
- User Carbon due to use of an asset.







'In use stage' in years (Buildings)	10	15	20	25	30	35	40	45	50
Main structure			■				■		
Plastering & Painting	■		■		■		■		
Thermal insulation layer					■				
Water supply & ventilation pipe					■				
Ceramic tiles					■				
Roofing			■				■		
Plastic steel windows					■				
Drain pipes					■				
HVAC maintenance	■	■	■	■	■	■	■	■	■

'In use stage' in years (Bridges)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Replacing wearing coat	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Resurfacing of the deck				■										■					
Rehabilitation of the deck									■										
Resurfacing of the piers				■										■					
Rehabilitation of the piers									■										
Resurfacing of the abutments				■										■					
Rehabilitation of abutments									■										
Resurfacing of crash barriers				■										■					
Rehabilitation of crash barriers									■										
Painting of steel components				■					■					■					
Cleaning of Expansion joints	■	■	■		■	■	■	■		■	■	■	■		■	■	■	■	■
Replacing of Expansion joints				■					■					■					
Replacing of bearings				■					■					■					
Replacing of railings				■					■					■					

Carbon calculations after 'End of Life' stage (B1-B9)

- Emissions due to the use of plant, equipment and vehicles. For deconstruction, dismantling or demolition of the assets
- Emission due to transporting of the waste materials to the landfill location for the purpose of disposing.
- Emission associated with treatment and processing for recovery, reuse and recycling of waste materials.
- Emissions due to the transportation of demolished materials to the recycling factory.
- Emissions due to the transportation of dismantled/deconstructed components to the storage yard.
- **However, there will be reduction in the carbon footprint due to the use of recycled materials and dismantled components.**

Status of Carbon emission in built environment

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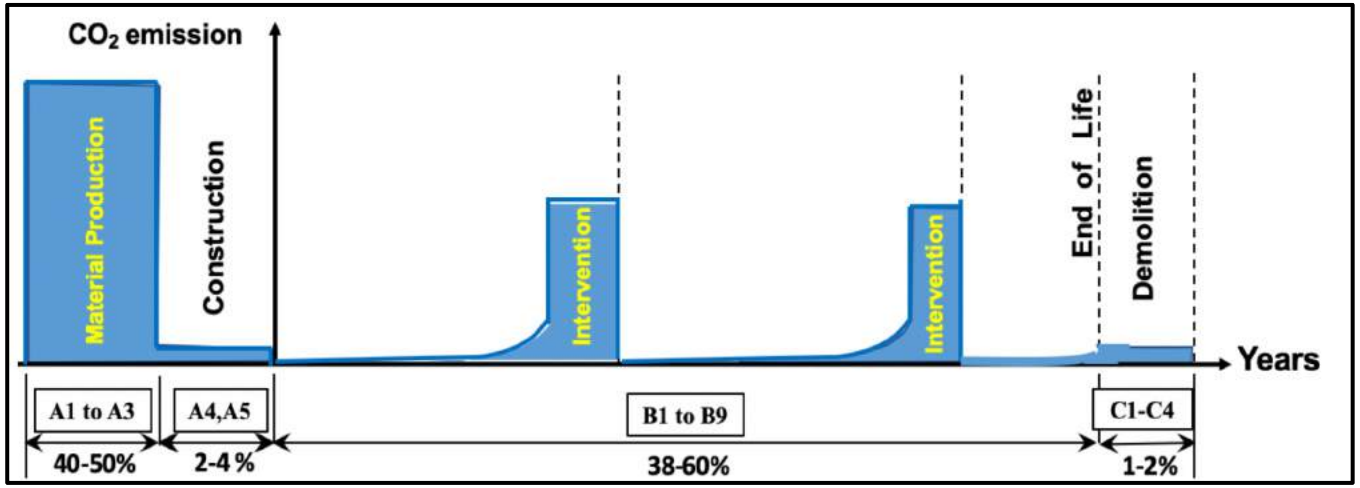


Materials/Activities	Kg CO_{2eq}/M^3 of concrete	% Of Total
Cement	391	87
Other ingredients	14	3
Materials transportation	22	5
Concrete production	7	1.6
Wastages	15	3.4
Total	450	100

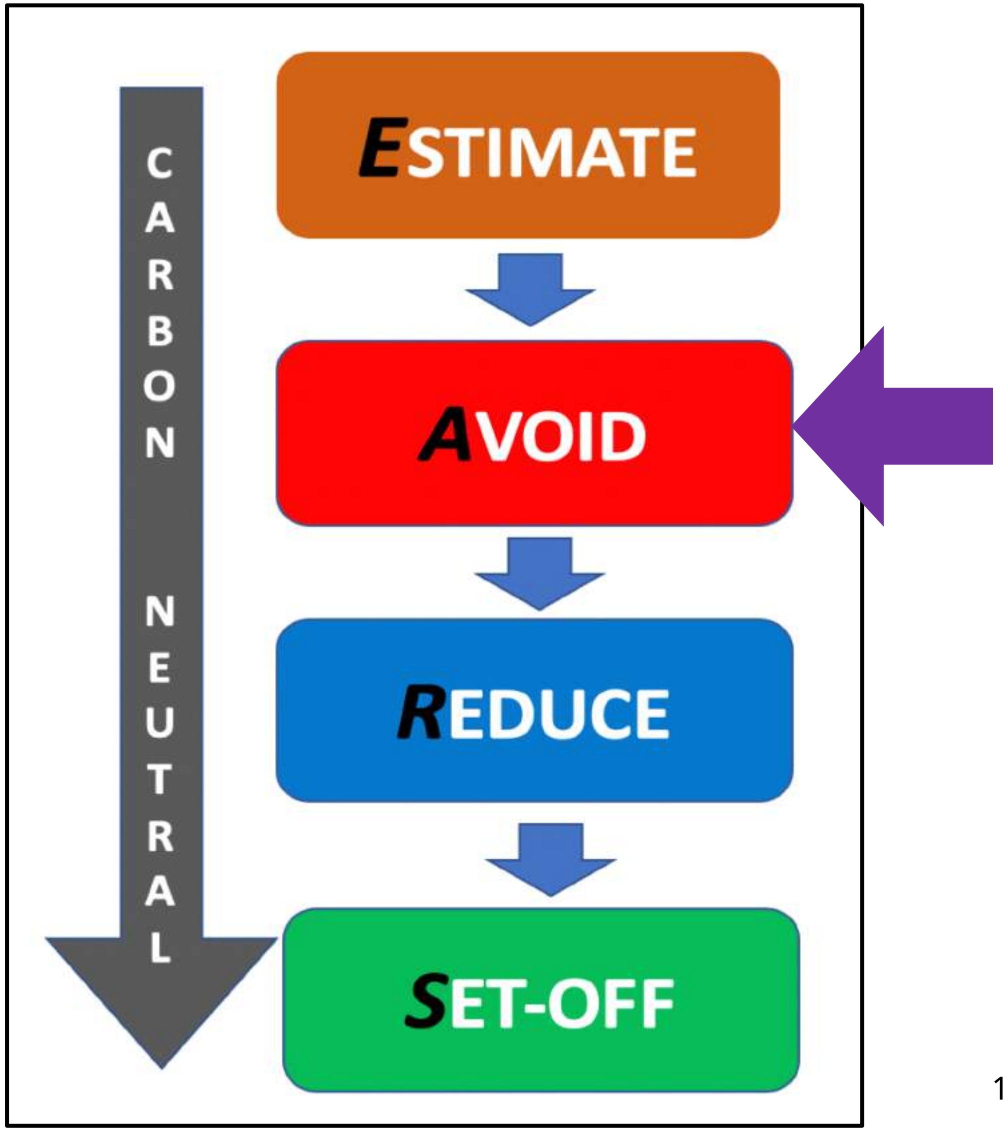
Materials	Av. t CO_2 for 31 buildings	% of the Total	% of the Total
Steel	324.1	26.68	79.31
Cement	633.33	52.14	
Aggregate	5.92	0.49	
Brick	154.79	12.74	12.74
PVC pipes	33.44	2.75	2.75
Tile	9.89	0.81	
Aluminium	24.19	1.99	
Sal wood	3.87	0.32	
Paints	3.81	0.31	
Glass	2.67	0.22	
Granite	18.72	1.54	
Total	1214.73	100.00	100

S.No	Description	Unit	Quantity	Carbon Factor (t CO_2/unit)	Carbon (t CO_2)	Concrete, Steel, others	Total (t CO_2)
1	**Superstructure**						70504 (63%)
	M 40 Concrete	m³	5712	0.153	874	17,208 (24.4%)	
	>M 50 Concrete	m³	91344	0.176	16077		
	Bituminous Concrete	m³	524	0.49	257		
	Steel Reinforcement	t	13362	2.61	34875	50,149 (71.1%)	
	HTS for prestressing including PT bars	t	4149	2.2	9128		
	Stay cable system including anchorages	t	1260	2.5	3150		
	100 mm Expansion Joints	m	56	0.14	8		
	440mm Expansion joints	m	266	0.61	162		
	Structural steel for central hinges & brackets in pylon, etc.	t	652	2.89	1884		
	Pot bearing < 100t	No	128	5.09	652		
	Pot bearing >600 t	No	8	25	200		
	HDPE sheathing ducts	m	17064	0.01	171	3,239 (4.5%)	
	Stone matrix Asphalt	m²	4586	0.026	119		
	Water proofing membrane	m²	1,28,832	0.012	1546		
	Protective coatings & Road markings	m²	3,40,892	0.0041	1398		
	Epoxy glue	t	0.8	5.7	5		
2	**Substructure & Foundations**						41027 (37%)
	M 25 concrete (Plugs & PCC)	m³	17270	0.131	2262	25,003 (61%)	
	M 40 Concrete (Wells & retaining structures)	m³	1,32,750	0.153	20311		
	>M 50 Concrete (Piers & Abutments)	m³	13805	0.176	2430		
	Steel reinforcement	t	4487	2.61	11711	13,985 (34%)	
	Structural steel for floating caissons & Cutting edges	t	787	2.89	2274		
	Sand filling inside caissons & Earthwork for artificial islands & retaining structures	m³	74607	0.024	1791	2,039 (5%)	
	Stone pitching for apron & Filter media	m³	6192	0.04	248		
3	**Construction Stage** :Fuel consumption for modules A4 to A5	Liters	1.2×10^7	0.0027	32,400		32,400 (29%)
4	**Contingency** : Adding 2 % contingency for accounting for omissions like geotextiles, utilities, lighting , modification for temporary works, etc.						2879
	Grand total of carbon emissions for the boundary system cradle to completion in t CO_2						**1,46,810**

> 90 % is because of cement & steel in concrete construction

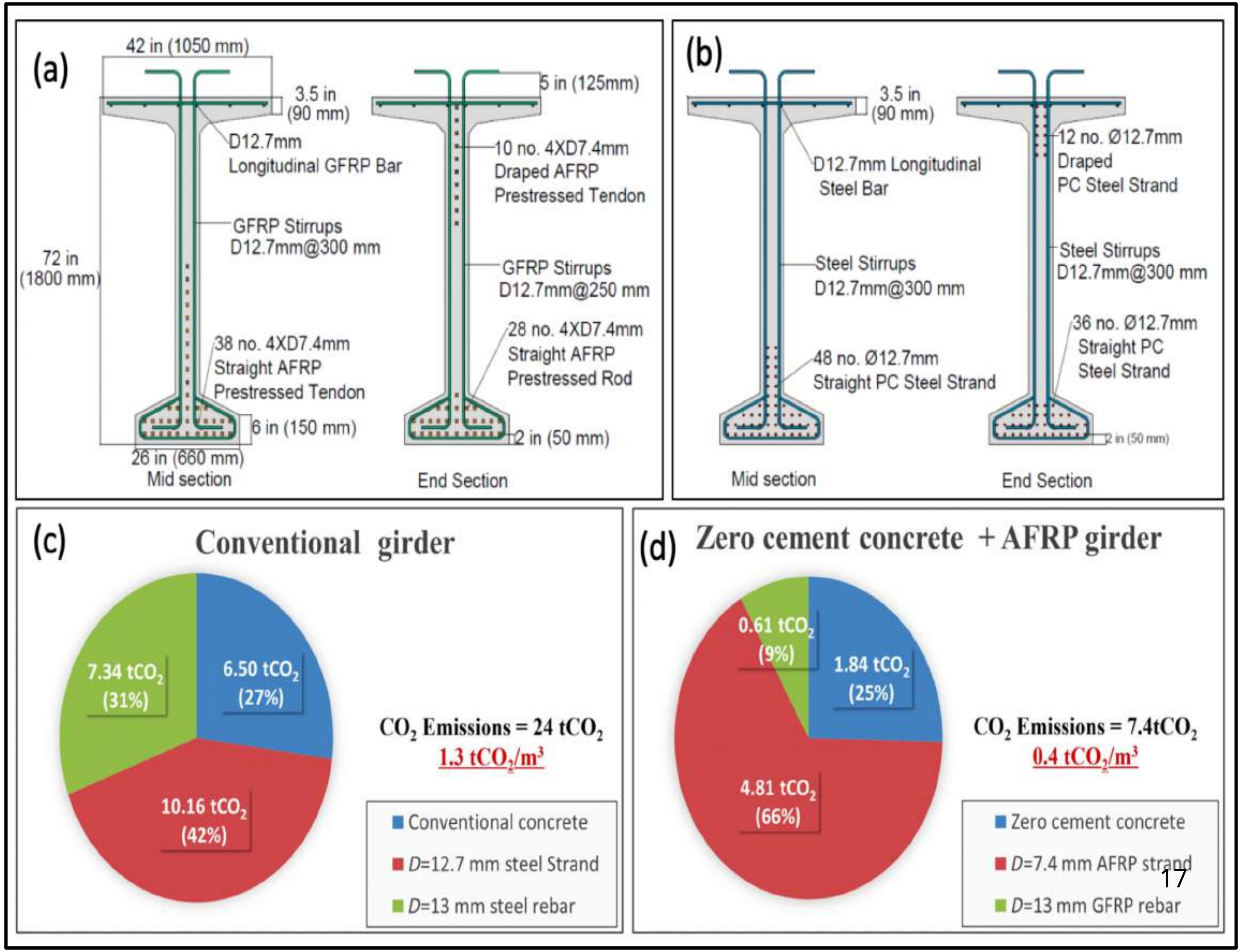
Avoidance of Carbon footprint

- ✓Complete avoidance of structures itself ????!!!!.
- ✓Avoidance of **Cement & Steel completely**.
- ✓Avoidance of **Non-Renewable energy consumption** in Construction & Operation.



Alternative to Rebars, steel strands & Cement

- However, OPC can be completely avoided in concrete by adopting zero-cement concrete and Geo polymer concretes
- Fiber-reinforced plastics (FRPs) such as carbon, aramid and basalt can be used as reinforcement materials and steel can be avoided.
- FRP can be used as prestressing tendons to avoid metallic prestressing strands.

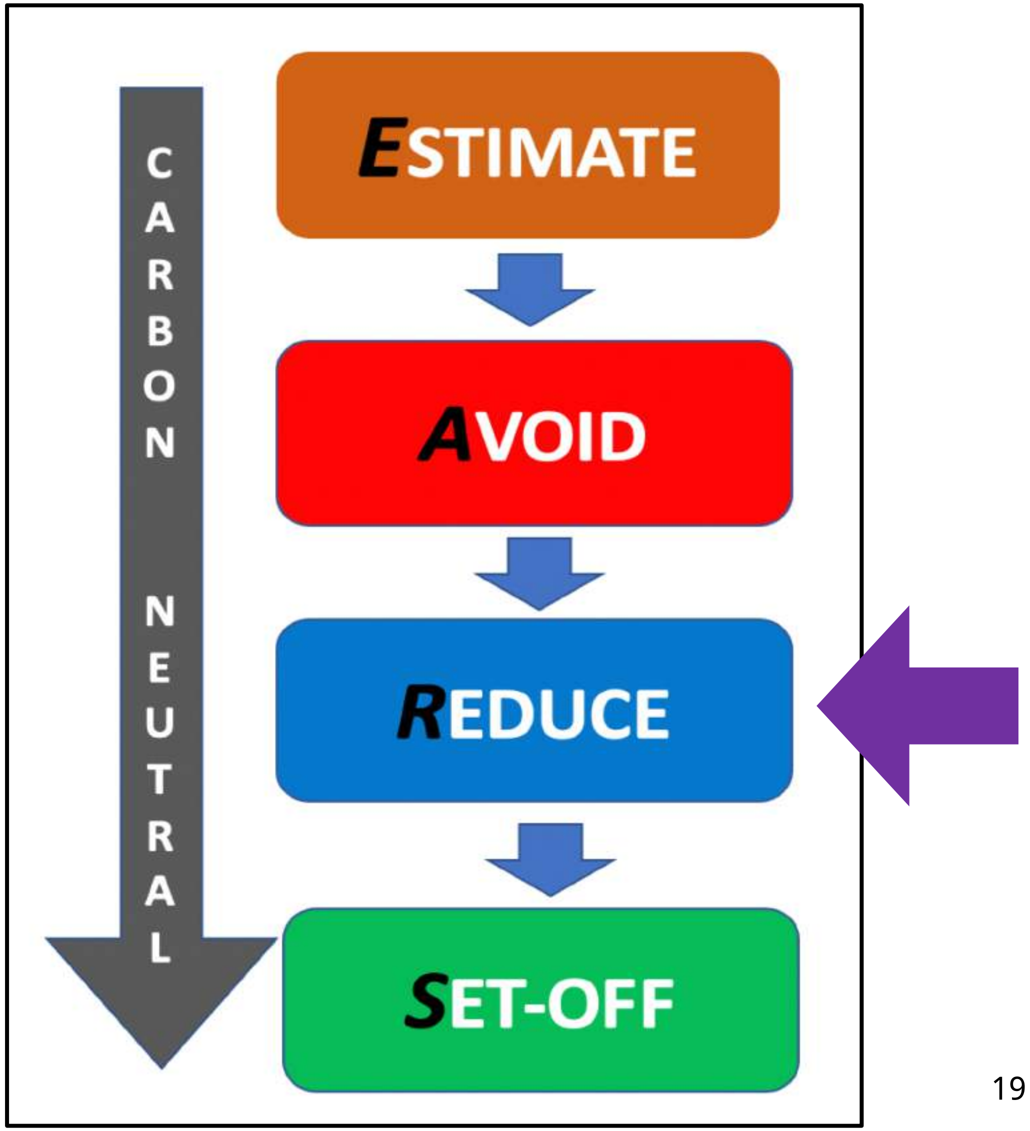


Avoidance of non-renewable energy sources

- The cement and steel having the electricity requirement of 5.5 GJ and 30.0GJ whose carbon factor being 0.197 t CO_{2eq}/GJ results in the emissions of 1.084 t CO_{2eq} and 5.91 t CO_{2eq} respectively.
- This is much higher than direct emission during the production of cement and steel which are 0.48 t CO_{2eq} and 2.25 t CO_{2eq} per t of cement and steel respectively.
- Even for the transportation of materials (A2 & A4 modules) and during the construction for operation of plants and equipment (A5 module),the non-renewable energy from fossil fuels are used culminating in carbon footprint.
- **One of the ways of reducing the carbon footprint is to completely avoid the consumption of non-renewable energy and shift over to renewable energy sources like, solar, wind, hydel, nuclear and bio-mass, etc.**
- **The cement and steel factories may be mandated to have their own captive power plants of renewable energy sources and use of green hydrogen.**

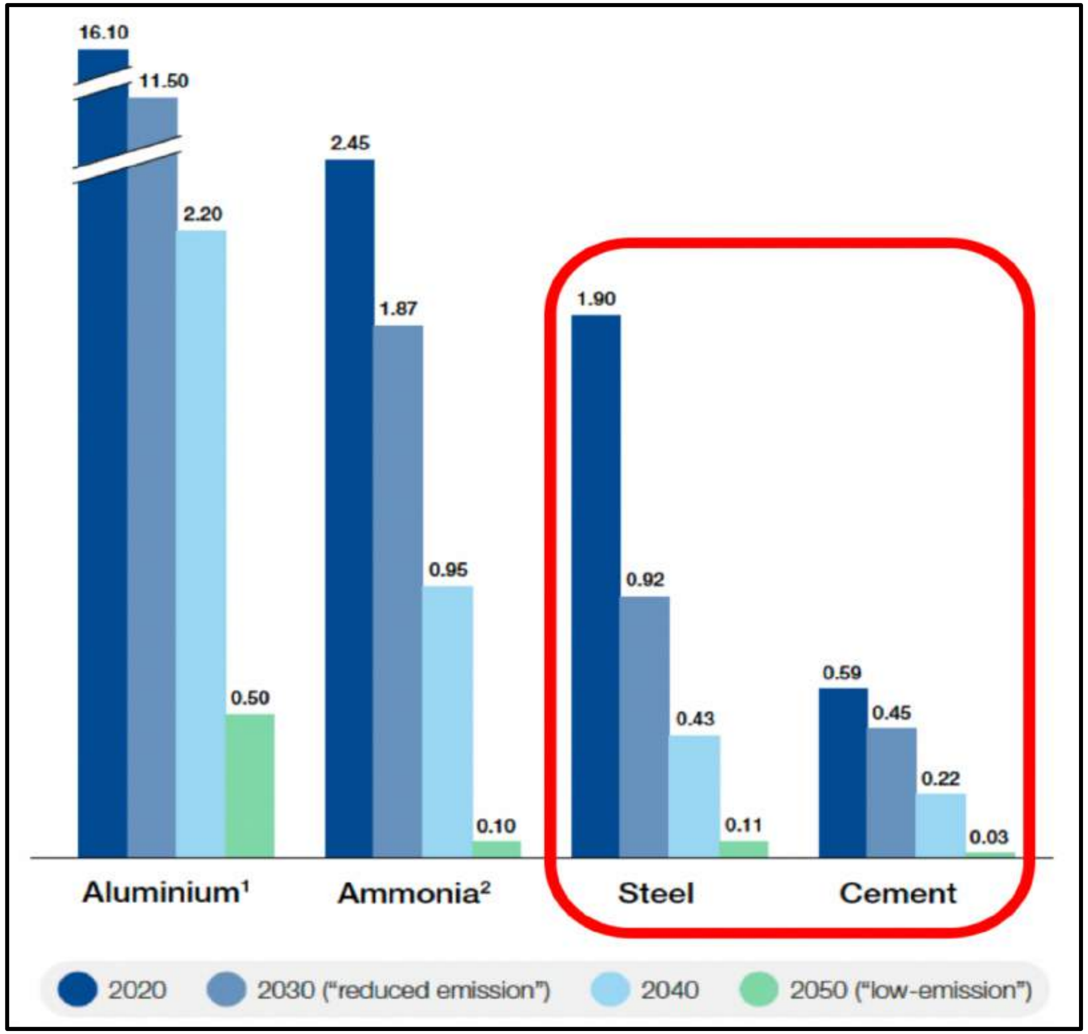
Reduction of Carbon footprint

- ✓Reduction of OPC content by replacement with SCMs.
- ✓Reduction by use of alternative steel to carbon steel.
- ✓Reduction of heat wastages during production of steel & cement.
- ✓Reduction by waste based product composition & upgradation of plants
- ✓ Reduction of interventions during service life by enhancement of durability.
- ✓Reduction by resilient structures.
- ✓Reduction by design efficiency.
- ✓Reduction by design for circularity.
- ✓Reduction of wastages during construction.
- ✓Reduction by policy making



Global strategies for net zero in Steel & Concrete construction

- More than 90 % of the capital carbon in construction is due to cement and steel.
- It is almost impossible to completely avoid non-renewable energy sources and also the clinker and coal in cement and steel making respectively.
- United Nations Framework Convention for Climate Change (UNFCCC) sets the target for industry emission trajectory in stages up to 2050 for various materials.



Basic materials industry carbon emission intensity trajectory in t CO_2/t (2020-2050)

Reducing Carbon by upgradation of plants & re-formulation of ingredients at product stage

Reducing EC at product stage

INDIA CHAPTER

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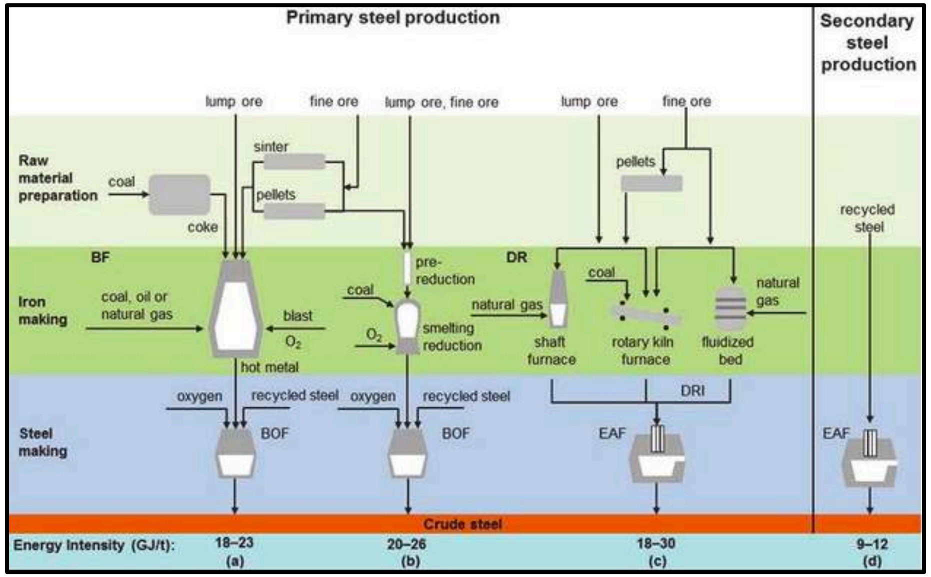
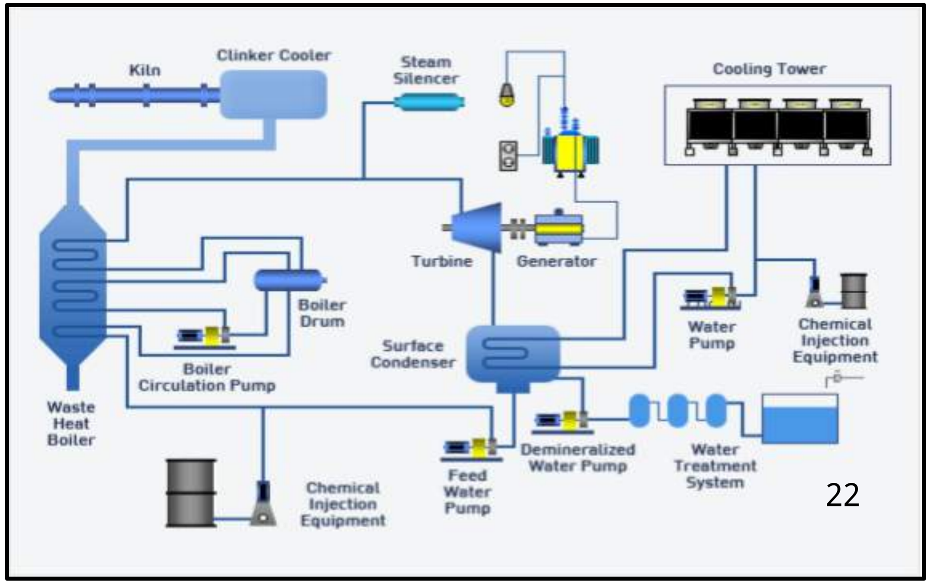
Heggade on ‘Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction’

- Despite the current energy efficiency, production of OPC consumes the energy of 5.5GJ /ton & steel consumes 30GJ/ton.
- EC in Cement due to EE is 67% while in steel is 72%.
- **The best way to completely eliminate this is by having captive power plants producing renewable electricity .**
- The cement emits directly 0.8t CO_2 per t while steel 2.5 t CO_2 against **0.03 and 0.11 respectively** as set out in UNFCCC report as a measure of net-zero by 2050.
- The direct emission should be brought down to that efficient level by :
  - Improving emission control by upgrading plants with the state of the art equipment.
  - Improving product formulation to reduce emission and minimize the use of natural resources.
  - Conduct research to develop new applications for improving emission efficiency.
- **WHRS (waste heat recovery system) has a potential to generate about 20% to 30% of plant power requirements (reducing purchased/captive power needs).** It uses hot gases from the clinker cooler or pre-heater to heat a liquid and generate steam, to generate in turn electricity for powering the cement plant.



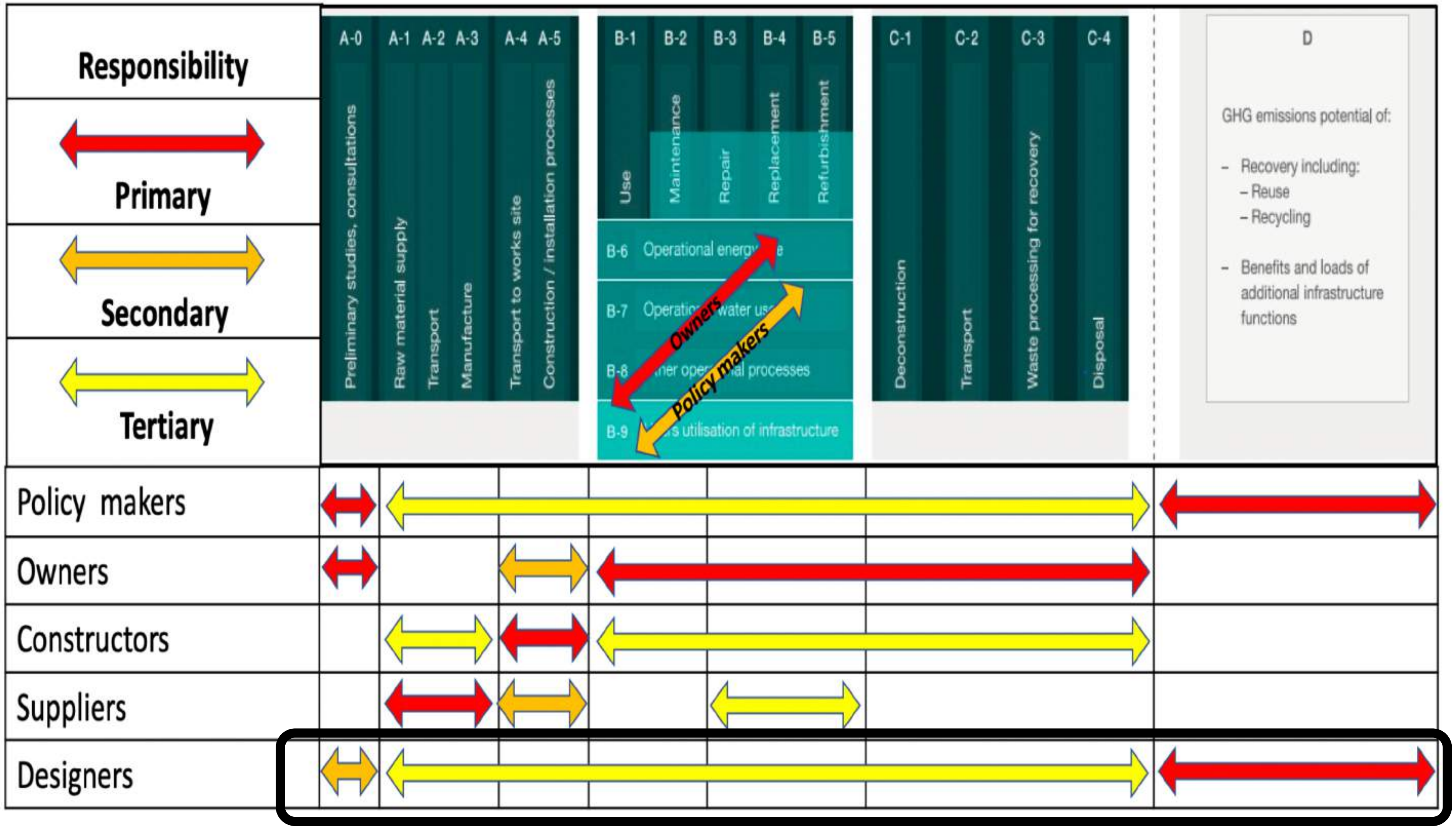


Policy making for carbon neutrality

Construction supply chain (EN15978)

Heggade on 'Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction'

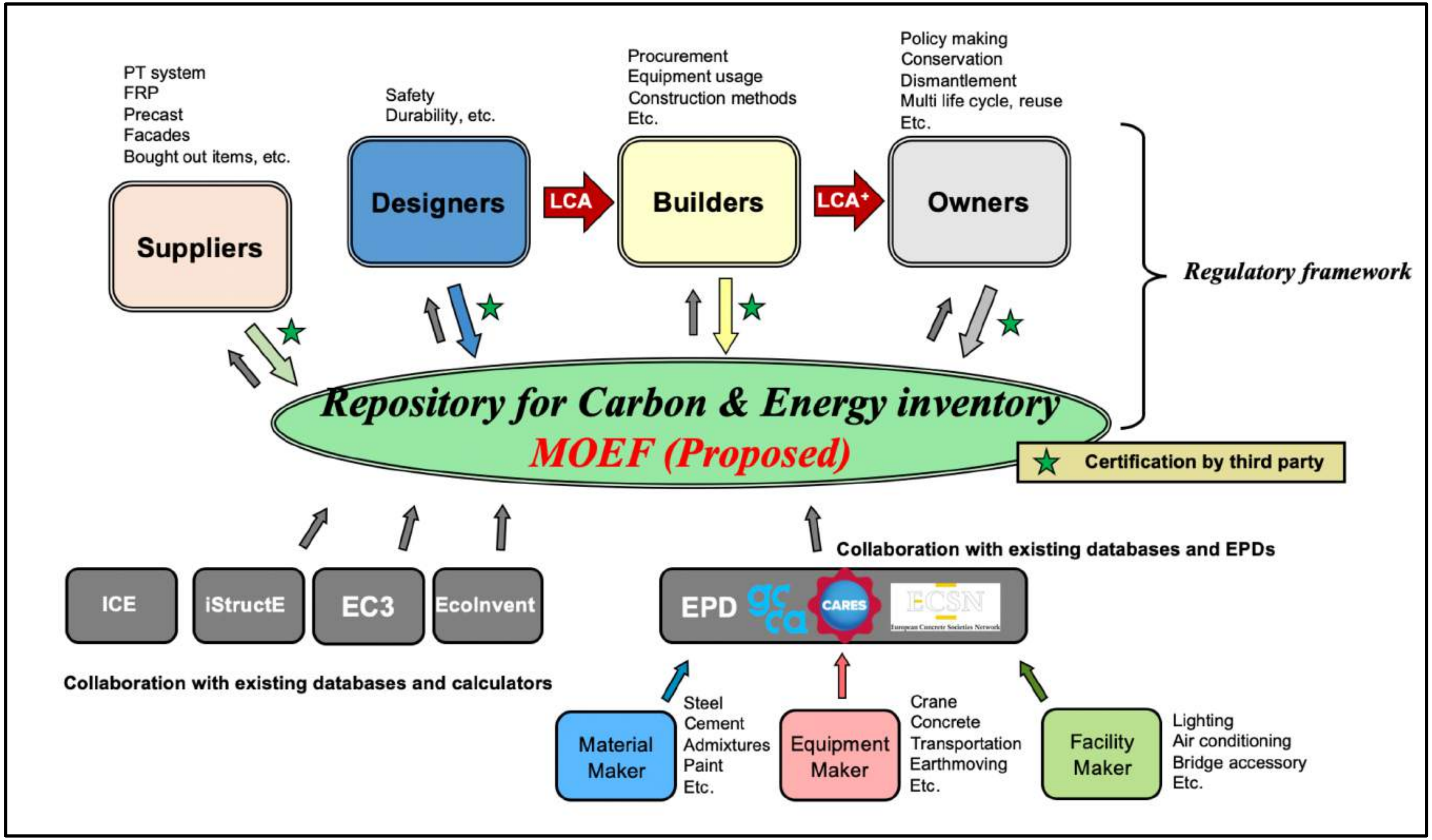
- In the construction supply chain based on Carbon Disclosure Project (CDP) and Science-Based Target (SBT), the responsibilities of various stake holders are given.
- The CO2 emissions classified as Scope 1 and 2 are the responsibility of the main players in each process.
- However, as long as they are integrated into this supply chain, some action is required for each player's Scope 3.
- **In particular, Policy makers & designers are involved throughout the LCA and are therefore required to provide low carbon and decarbonization proposals in the LCA.**



Responsibility matrix in construction supply chain of various stakeholders

Proposed structure for creating Carbon Inventory

- In India, there is an urgent need to have an updated carbon inventory which is vital for achieving carbon neutrality by 2070.
- In 2017, International Finance Corporation (IFC) in consultation with some manufacturers, developers and suppliers brought out a first version of carbon factors.
- However, the consultation of wide nos. of stake holders is necessary and also bring the same into regulatory frame work.



Source : The model presented by Dr Akio Kasuga in fib SAG meeting on 14/04/2023 is modified by the author to suit India

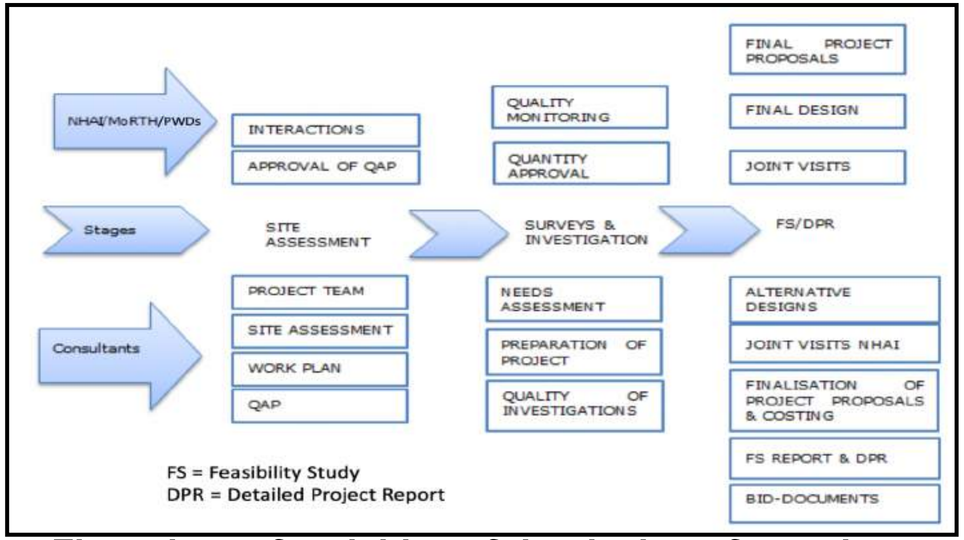
EPD = Environmental Product Declarations (ISO 14044 & EN 15804)]

- An Environmental Product Declaration - EPD is a **registered document** that communicates transparent and analogous information about the **life cycle environmental performance of any manufactured products**.
- It gives accurate, reliable and systematic environmental information for product. **ISO 14025** is referred document for EPD, where it is referred as "type III environmental declarations".
- This was available in 2002. During the 10 years span, differences and controversies in the declaration document lead to **introduction of more rigorous rules for the building sector known as EN 15804.**
- This document provides modular framework for EPD of product.
- ***Many countries have regulatory framework or legislation for manufacturers to declare the EPDs which has to be introduced in India at the earliest for carbon neutrality.***

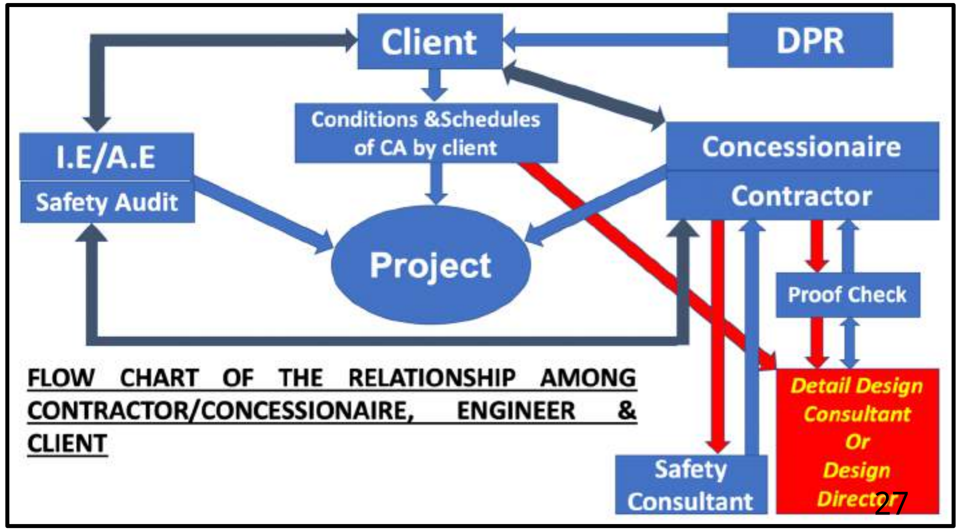
Source : EPD In accordance with ISO 14025 and EN 15804:2012+A2:2019 for Steel bar from TATA Steel Ltd

’QCSBS’ Procurement system

- Presently in DPR & AE consultancies ‘QCBS’ system (Quality & Cost Based System) is followed for procurement in which 70% weightage is given to quality and 30% to cost.
- ***The author proposes ‘QCSBS’ system (Quality, Cost & Sustainability System) where weightages should respectively be 40:20:40.***
- ***This has to be extended to EPC Contract procurement too which is presently based on least cost system.***
- For ‘Sustainability’ weightage, threshold limits for the carbon contents may be specified.



Flow chart of activities of the design of a project



EPC Contract model

Standards & Codes making

- Review safety factors to make the structures less carbon embodied.
- Rationalisation of over specifications of designed loads.
- Moving over to performance based specifications from prescriptive specifications.
- Guidelines for extending the life of bridges and other structures.
- Allow Composite piles & piled footings for pile foundations.
- ***The idiosyncrasy among the standards and code makers that the construction deficiencies have to be factored in "factor of safeties" should not have any place in the era of climate action.***

STANDARD SPECIFICATIONS
AND
CODE OF PRACTICE FOR ROAD BRIDGES

SECTION V
STEEL ROAD BRIDGES
(LIMIT STATE METHOD)
(Third Revision)

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MAY 2010

Standards & Codes making

INDIA CHAPTER

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- 40 mm and down aggregates has the potential of cement saving to the tune of 8 to 10% by virtue of its larger surface .
- The following manufactured aggregates is encouraged in IS:383 :
  - Iron Slag Aggregate
  - Steel Slag Aggregate
  - Copper slag as aggregates
  - Construction and demolition (c&d) waste (Recycled)
- The restrictions on usage of mineral admixtures which are industrial wastes as a by-product should be removed.

Table 1 Extent of Utilization
(*Clause* 4.2.1)

Sl No.	Type of Aggregate	Maximum Utilization		
		Plain Concrete Percent	Reinforced Concrete Percent	Lean Concrete (Less than M15 Grade) Percent
(1)	(2)	(3)	(4)	(5)
i)	Coarse aggregate:			
a)	Iron slag aggregate	50	25	100
b)	Steel slag aggregate	25	Nil	100
c)	Recycled concrete aggregate[1] (RCA) (*See* Note 1)	25	20 (Only upto M25 Grade)	100
d)	Recycled aggregate[1] (RA)	Nil	Nil	100
e)	Bottom ash from Thermal Power Plants	Nil	Nil	25
ii)	Fine aggregate:			
a)	Iron slag aggregate	50	25	100
b)	Steel slag aggregate	25	Nil	100
c)	Copper slag aggregate	40	35	50
d)	Recycled concrete aggregate[1] (RCA) (*See* Note 1)	25	20 (Only upto M25 Grade)	100

[1] *See* **A-3** for brief information on recycled aggregates (RA) and recycled concrete aggregates (RCA).

NOTES

1 It is desirable to source the recycled concrete aggregates from sites being redeveloped for use in the same site.

2 In any given structure, only one type of manufactured coarse aggregate and one type of manufactured fine aggregate shall be used.

3 The increase in density of concrete due to use of copper slag and steel slag aggregates need to be taken into consideration in the design of structures.

4 While using manufactured aggregate as part replacement for natural aggregate, it should be ensured that the final grading meets the requirements specified in Table 7, Table 8 and Table 9.

MINISTRY OF ROAD TRANSPORT & HIGHWAYS
SPECIFICATIONS FOR ROAD AND BRIDGE WORKS
(Fifth Revision)

601 DRY LEAN CEMENT CONCRETE SUB-BASE

601.3.3 **Cement Content**

The cement content in the dry lean concrete shall be such that the strength specified in Clause 601.3.4 is achieved. The minimum cement content shall be 150 kg/cu.m of concrete. In case flyash is blended at site as part replacement of cement, the quantity of flyash shall not be more than 20 percent by weight of cementitious material and the content of OPC shall not be less than 120 kg/cu.m.

602 CEMENT CONCRETE PAVEMENT

602.3.2 **Cement Content**

When Ordinary Portland Cement (OPC) is used the quantity of cement shall not be less than 360kg/cu.m. In case fly ash grade I (as per IS:3812) is blended at site as part replacement of cement, the quantity of fly ash shall be upto 20 percent by weight of cementitious material and the quantity of OPC in such a blend shall not be less than 310 kg/cu.m. The minimum of OPC content, in case ground granulated blast furnace slag cement blended, shall also not be less than 310 kg/m³. If this minimum cement content is not sufficient to produce concrete of the specified strength, it shall be increased as necessary by the contractor at his own cost.

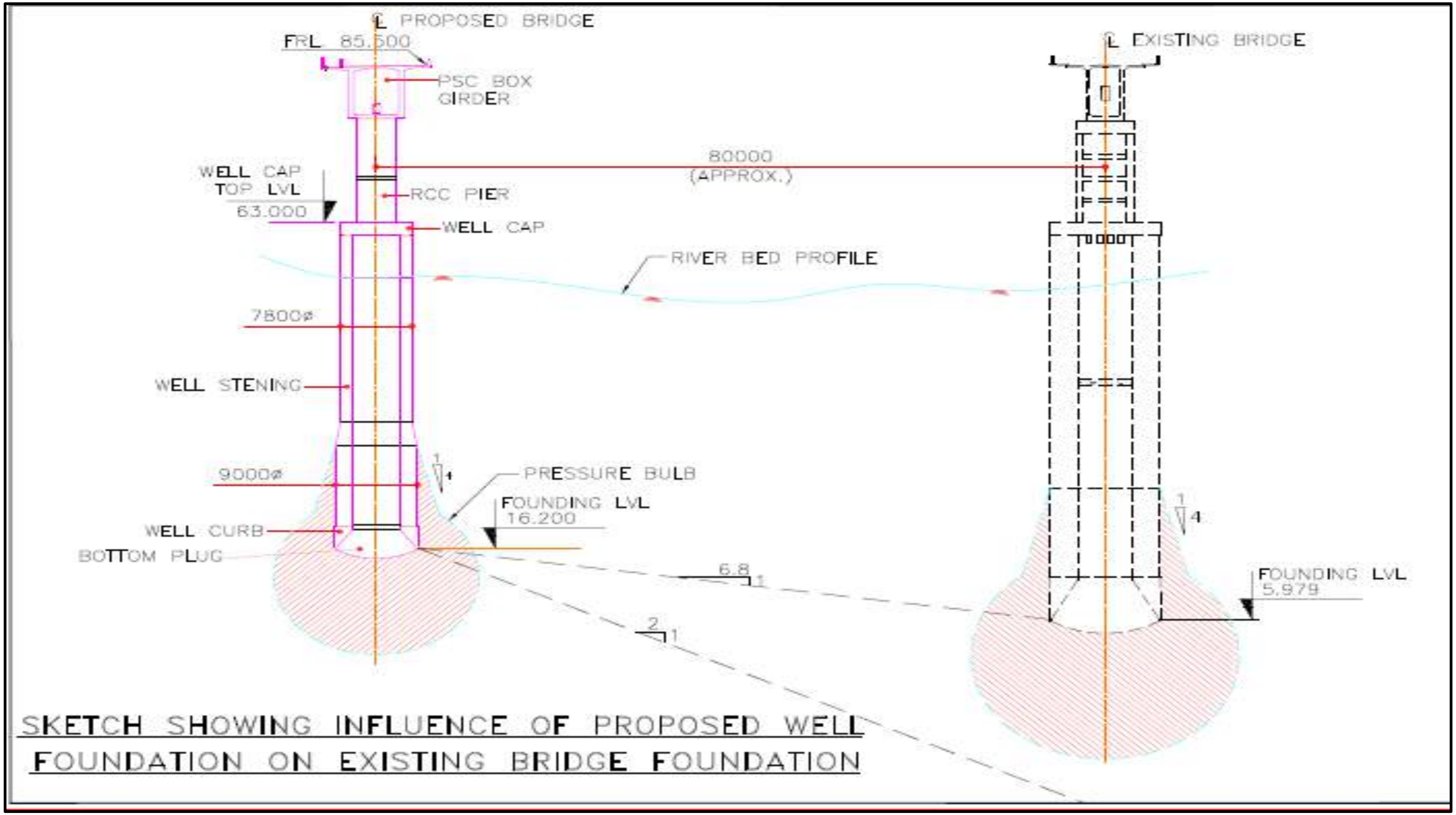
Illustration of carbon intensive code provision

705.1 General

The foundation shall be designed to withstand the worst combination of loads and forces evaluated in accordance with the provisions of Clause 706. The foundations shall be taken to such depth that they are safe against scour or protected from it. Apart from this, the depth should also be sufficient from consideration of bearing capacity, settlement, liquefaction potential, stability and suitability of strata at the founding level and sufficient depth below It. In case of bridges where the mean scour depth 'dsm' is calculated with Clause **703.2**, the depth of foundation shall not be less than those of existing structures in the vicinity.

Keeping the founding level of new bridge same as the existing Bridge

Heggade on 'Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction'



INDIA CHAPTER

IMPACT ON CARBON FOOTPRINT

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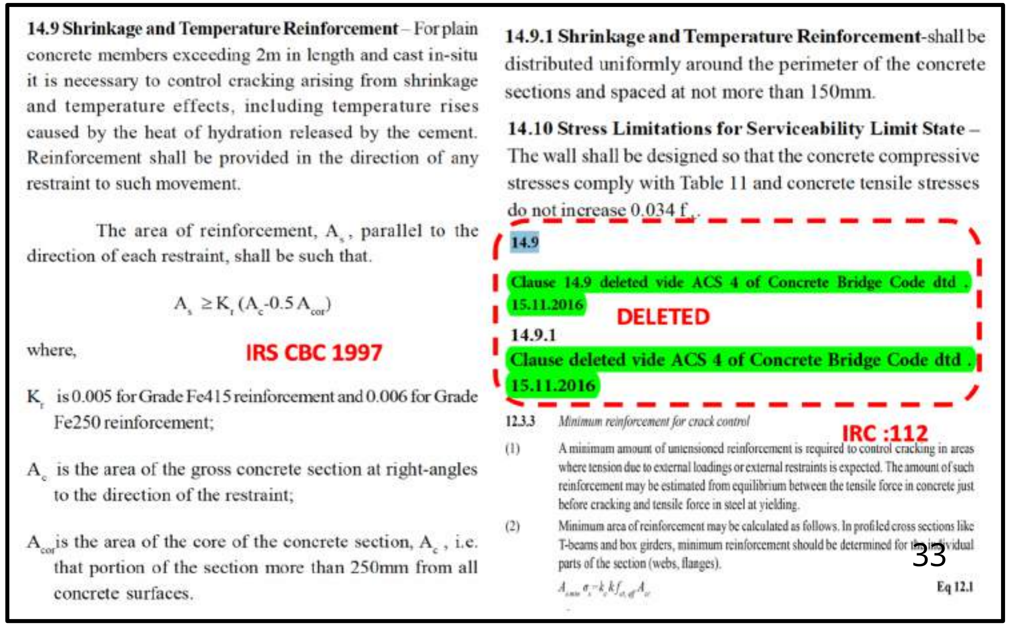
- In almost 24 nos. of wells additional depth of foundation was almost 10m for each foundation.
- This means enormous time over run, cost over run, unnecessary waste of energy and CO_2emissions to environment.
- The above could have been utilised for creation of more infrastructure in the country to support so many house holds.

Description	unit	Additional Impact	Embodied Energy (GJ)	CO_2 em'n (t eq)	Remarks
Sinking	m	229.10	572.75	11.445	70355.55 GJ energy can sustain 3257 families per annum in India & 5533 t CO_2 emission to environment could have been avoided.
Concrete	m^3	10229.33	57284.25	4807.79	
Steel	t	357.1	12498.5	714.2	
Total			70355.50	5533.44	

Unsustainable provisions in IRS codes & standards

- In India, there are 3 bodies of code making, VIZ. BIS, IRS & IRC among which IRC seems to be vibrant and updated to international standards.
- However, there is a need to rationalize all these bodies to single platform from sustainability point of view.
- In railway codes, even now mineral admixtures are not permitted as replacement to OPC which not only make structures vulnerable to durability but also highly carbon intensive.
- For land based, structures for the piles only end bearing is permitted neglecting friction capacity.
- The provision for minimum reinforcements in lightly reinforced concrete is withdrawn.
- ***There is a strong need to look at the code making process itself in IRS.***



14.9 Shrinkage and Temperature Reinforcement – For plain concrete members exceeding 2m in length and cast in-situ it is necessary to control cracking arising from shrinkage and temperature effects, including temperature rises caused by the heat of hydration released by the cement. Reinforcement shall be provided in the direction of any restraint to such movement.

The area of reinforcement, A_s, parallel to the direction of each restraint, shall be such that.

$$A_s \geq K_r (A_c - 0.5 A_{cor})$$

where,

IRS CBC 1997

K_r is 0.005 for Grade Fe415 reinforcement and 0.006 for Grade Fe250 reinforcement;

A_c is the area of the gross concrete section at right-angles to the direction of the restraint;

A_{cor} is the area of the core of the concrete section, A_c, i.e. that portion of the section more than 250mm from all concrete surfaces.

14.9.1 Shrinkage and Temperature Reinforcement-shall be distributed uniformly around the perimeter of the concrete sections and spaced at not more than 150mm.

14.10 Stress Limitations for Serviceability Limit State – The wall shall be designed so that the concrete compressive stresses comply with Table 11 and concrete tensile stresses do not increase 0.034 f_{ck}.

14.9

Clause 14.9 deleted vide ACS 4 of Concrete Bridge Code dtd . 15.11.2016

DELETED

14.9.1

Clause deleted vide ACS 4 of Concrete Bridge Code dtd . 15.11.2016

12.3.3 *Minimum reinforcement for crack control*

IRC :112

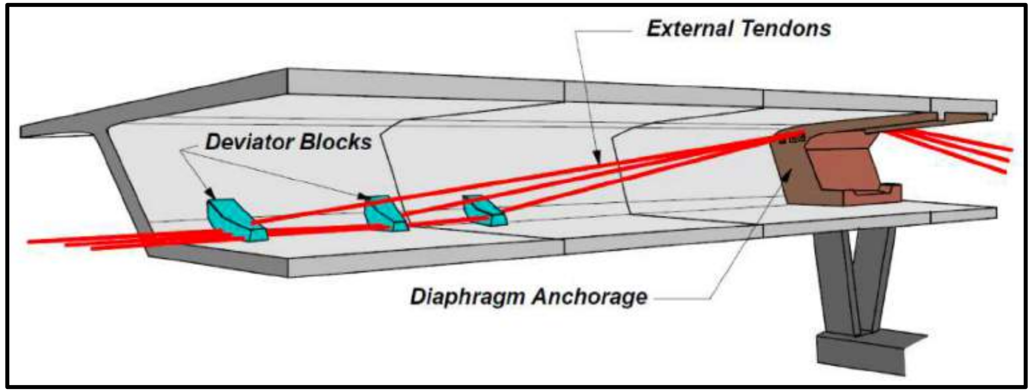
(1) A minimum amount of untensioned reinforcement is required to control cracking in areas where tension due to external loadings or external restraints is expected. The amount of such reinforcement may be estimated from equilibrium between the tensile force in concrete just before cracking and tensile force in steel at yielding.

(2) Minimum area of reinforcement may be calculated as follows. In profiled cross sections like T-beams and box girders, minimum reinforcement should be determined for the individual parts of the section (webs, flanges).

$$A_{s,min}\,\sigma_s = k_c\,k\,f_{ct,eff}\,A_{ct} \qquad \text{Eq 12.1}$$

External prestressing with dry joints

- Indian codes & guidelines discourages external prestressing which is against the principle circular economy
- Assuming, that there are 13 joints in a span of 40m, including temporary prestressing the total time required for epoxy application is 13 hours.
- After the last joint is prestressed, the pressure needs to be maintained for 24 hours. This means the total activity of the epoxy application requires 37 hours for a 40-m span.
- Based on this, the additional time required for 10 km elevated corridor, the time required for epoxy-related applications will work out 385 days.
- For one joint having 15 m^2 surface area, assuming 3mm thick epoxy glue, total quantity of epoxy glue will be 150 m^3 (around 6.5 kg/m^2) for 10km viaduct. The cost of the epoxy application including labour will be Rs 5.0 Cr.



Co-ordination among different policy makers (authorities)

- It is possible to have multi modal transport system on the same substructure & foundations in the water bodies.
- In bridges especially in rivers & creeks, the foundations are found to be highly Carbon intensive.
- The double decker structural system for highways and rail transport minimises the embodied carbon footprint and also construction stage related carbon to a large extent.
- **Policy makers should be carbon neutrality oriented.**

Mumbai trans-harbour link, Mumbai

Bogibeel Bridge, Assam- 125m

Hutong Yangtze River Bridge, 1092m

Changtai cross-river bridge, 1176m

Mandatory Green certification for Buildings & Infrastructure

- India secures third place in US Green Building Council's (USGBC) LEED certification list for 2023. LEED (Leadership in Energy and Environmental Design). India has 248 certified projects cover 7.23 million square meters.
- The Indian Green Building Council (IGBC), part of the Confederation of Indian Industry (CII) was formed in the year 2001.
- Some of the Central and State Government agencies have given recognition to IGBCs' Green Rating Systems.
  - ✓**IGBC NET ZERO ENERGY BUILDINGS**
  - ✓**IGBC NET ZERO WATER BUILDING**
  - ✓**IGBC Net Zero Waste Rating System for Buildings & Built Environment**
  - ✓**IGBC's Guidance Framework for Net Zero Carbon Buildings**

Design Efficiency for carbon neutrality

INDIA CHAPTER

Carbon Value Engineering (CVE)

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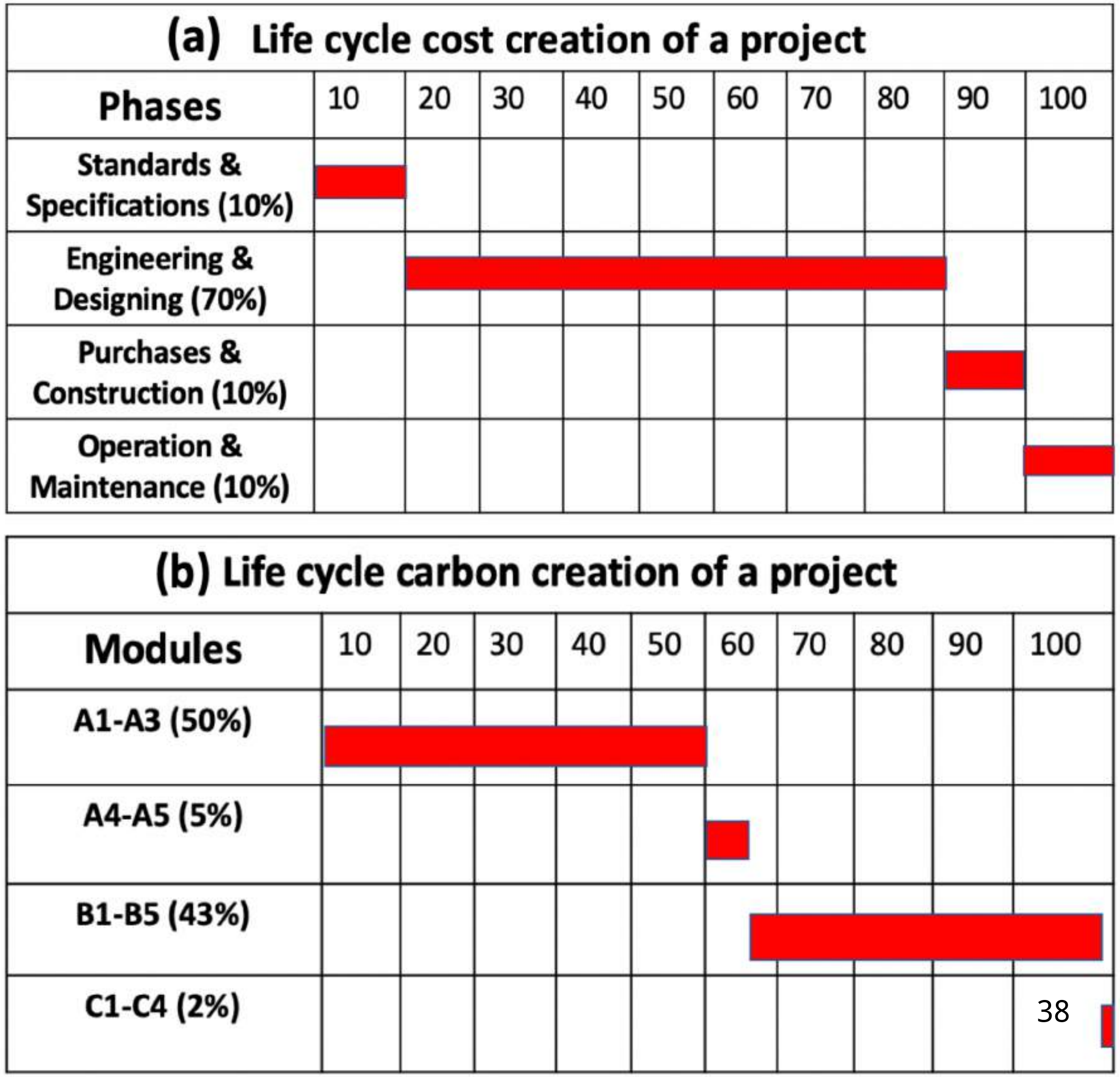
- "***Value Engineering*** is a methodology used to analyze the function of the goods and services and to obtain the required functions of the user at the lowest total cost without reducing the necessary Quality of Performance".
- The concept of the **Value Engineering** shall be extended to "**Carbon Value Engineering**" also where 50% (A1-A5)& 47% (B1-B5) of the carbon footprint of the project is created during Design & Engineering phase.
- By Carbon Value engineering for (A1-A2), it should be possible to reduce carbon footprint by 15 to 20%.
- Encourage Design-Build EPC contracts to enable Carbon Value Engineering



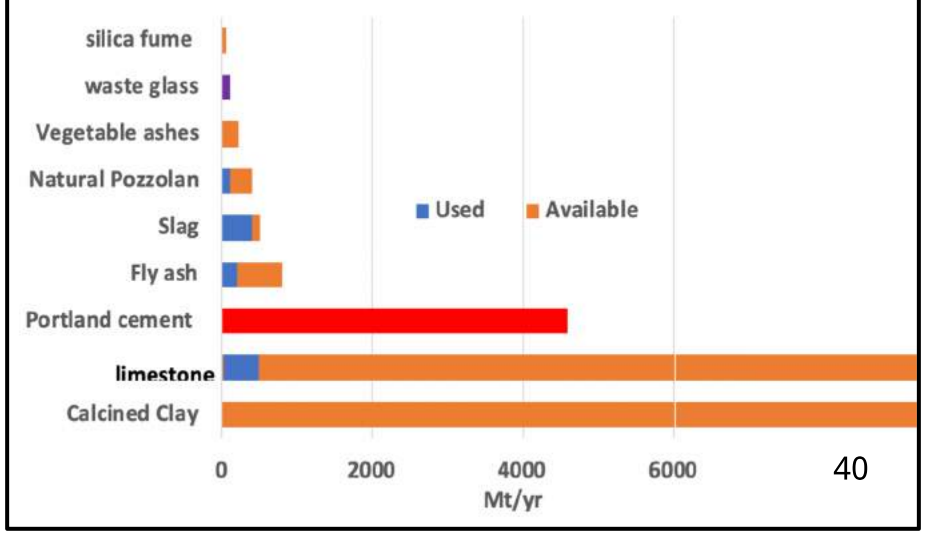
Design efficiency strategies for Concrete structures

- Reducing over-specification, e.g. more efficient and less conservative design
- Reducing over-specification of design loads
- Proper capacity forecasting for service which may hamper future expansion and flexibility
- Structural configuration (Section and profile) optimization that tailors components to their required functionality.
- Adopting structural forms and systems that are light and durable.
- Using higher-strength concrete and steel to facilitate the use of lighter members.
- Designing for constructability to avoid mishaps during construction and also for durable construction.
- Extending the lifetimes of structures, e.g. by designing for adaptability, designing for internal flexibility and designing for partial replacement of deteriorated components.
- Designing for circularity, e.g. reusability, recyclability, deconstruct ability, recoverability, prolong ability and scalability.
- Performance based design approach to have minimum interventions during service life rather than prescriptive design approach.

Slag aggregate & Cement as replacement to OPC

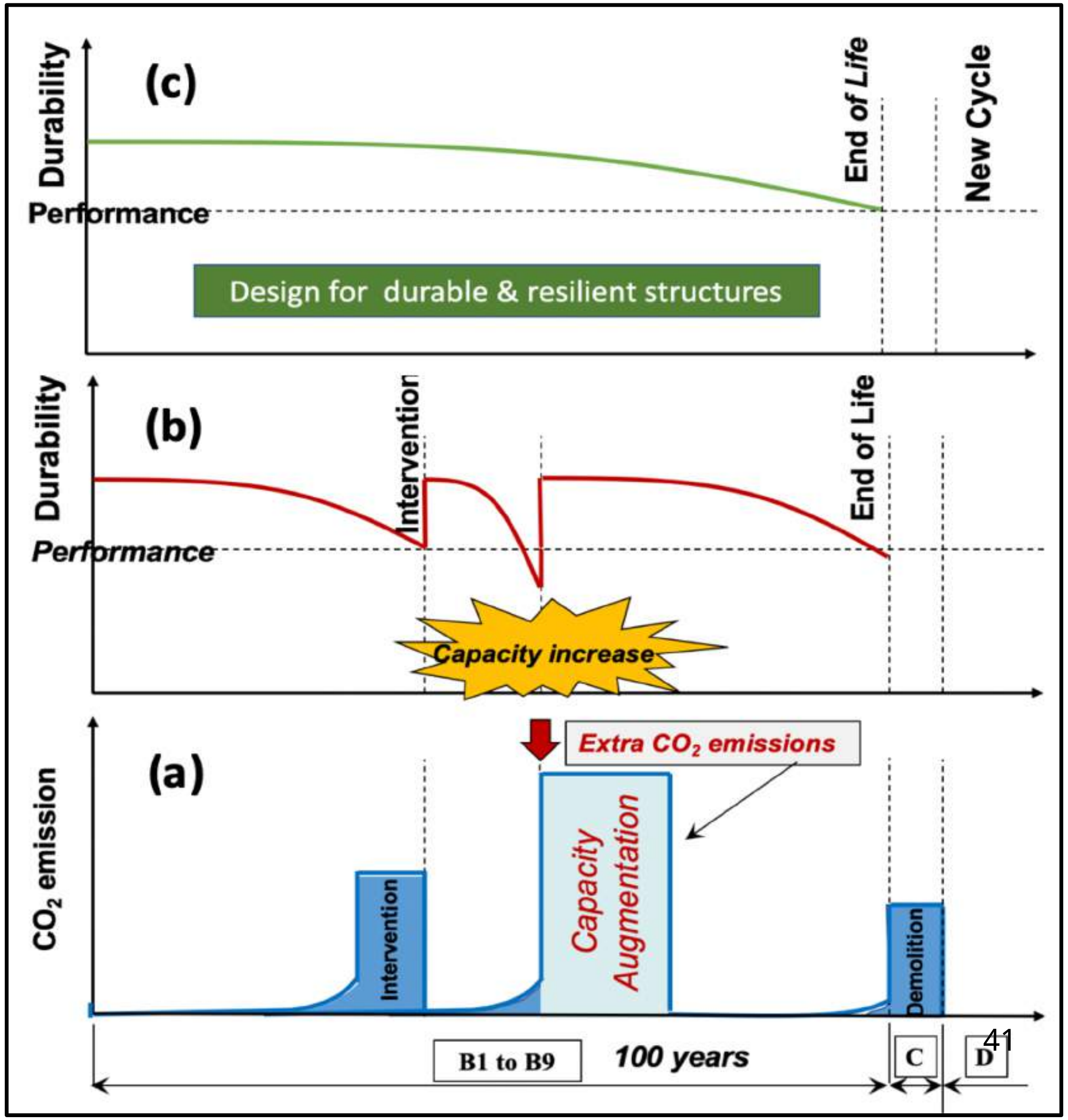
- In the concrete **OPC** should be avoided to the extent possible as the same is responsible for **90% EC in the concrete.**
- If can’t completely be avoided, has to be replaced to the max. extent by other SCM.
- Even the aggregates can be replaced with recycled and manufactured aggregates as per IS :383.
- **OPC replacement can be achieved by partially substituting cement by industrial by products otherwise ‘Industrial wastes’**
  - **Fly ash : Residual of coal combustion**
  - **Ground Granulated Blast Furnace Slag (GGBFS) : By product of steel industry**
  - **Silica Fume : By product of melting to produce silicon and Ferro-silicon alloys**
  - **Ultrafine slag**
  - **Ultra fine fly ash**
  - **Metakaoline**
  - **Rice husk**
  - **Calcined Clay (Available in plenty)**

	GHG EMISSIONS SYNTHESIS in kg eq CO2/m3 of concrete	
87%	Cement	391
2%	Other input materials	9
6%	Input materials transportation	27
2%	Concrete fabrication	7
0%	(Fresh + Precast) concrete transportation	0
3%	Site concrete losses	13
100%	TOTAL / Concrete delivered on site	**448**



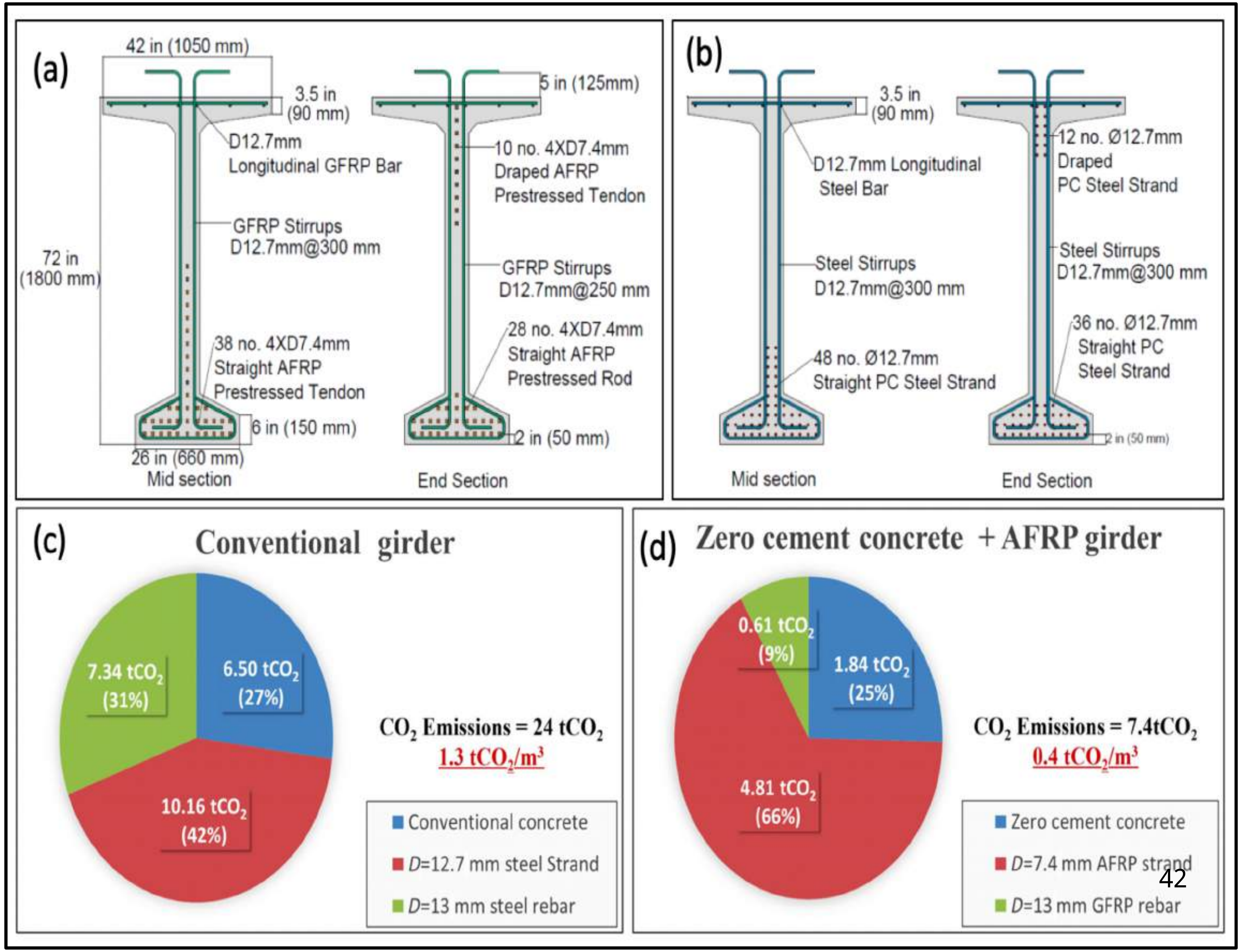
Design for durability & resilience in 'In Use' (B1-B5)

- In 'In use' stage of life cycle, the CO2 emissions are reported to be 40-60% and Dr Kasuga reports 60% in Japan.
- The corrosion of steel is the phenomena with which engineers have not found a concrete answers yet.
- Many of the bridges are already (Ganga bridge at Patna, Vashi creek bridge, etc.) replaced and many more are required to be replaced in future within service life which may double the CO2 emissions in (B1-B5) stage.
- The answer to overcome this deterioration phenomena could **be UHPC, FRP bars & strands, stainless steel, weathering steel,** etc.
- The climate change effects resulting in extreme events warrant new probabilistic models for design of resilient structures.



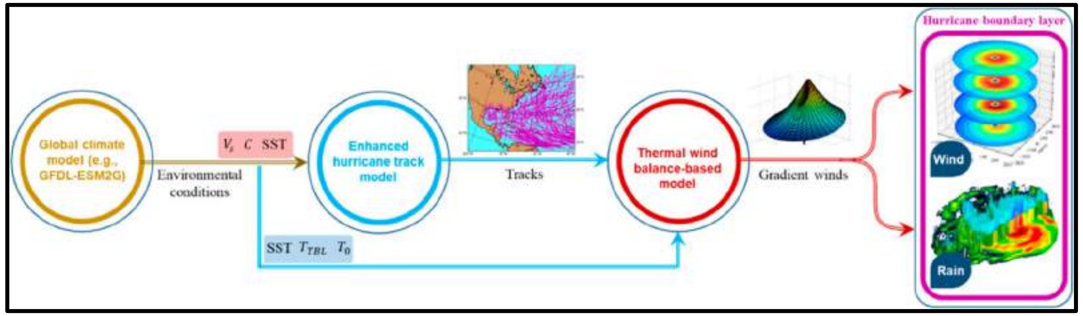
Alternative to Rebars, steel strands as tendons

- The biggest challenge in concrete is how to prevent rebars & tendons from deterioration
- Currently available technology, such as stainless steel or aluminium reinforcement and coated steel re-bars, can be used to some extent.
- Increasingly, fiber-reinforced plastics (FRPs) such as carbon, aramid and basalt are being used as reinforcement materials.
- FRP can be used as prestressing tendons as well as reinforcement materials.

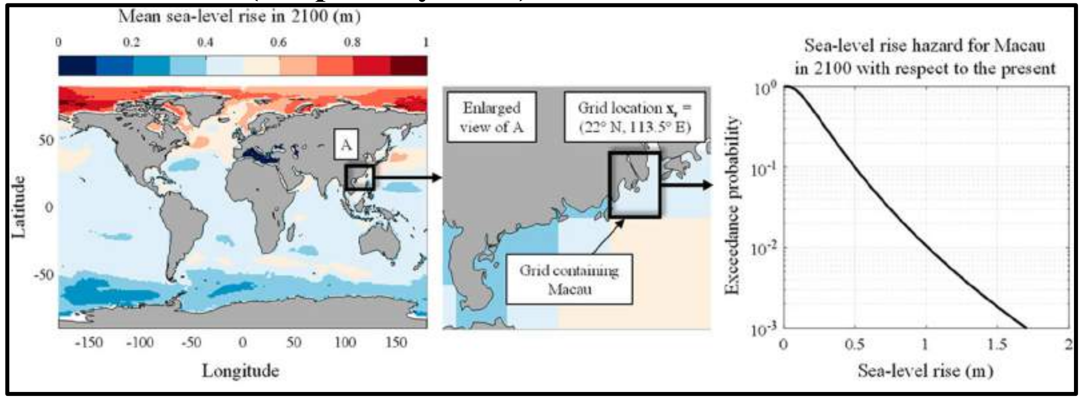


Climate change effects on structural actions

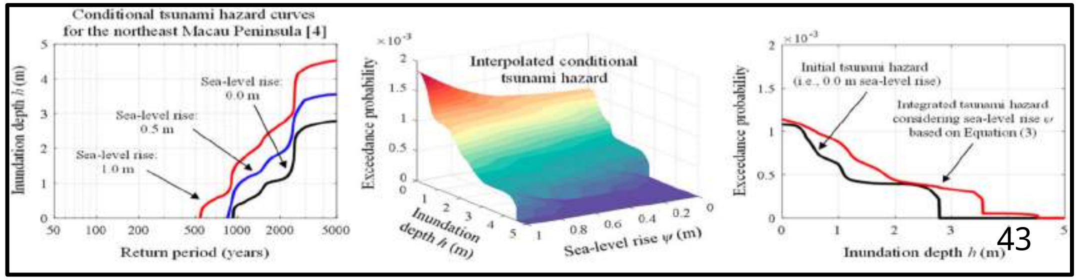
- The effects of climate change will require the **resilient structures** to avoid the interventions in ‘In use stage’
  - ✓ **Effects on landslides & Avalanches**
  - ✓ **Effects on river flooding**
  - ✓ **Effects on flow velocity in rivers & Risk of scouring**
  - ✓ **Effects of higher expected temperature**
  - ✓ **Effects of sea level increase on coastal infrastructure**
- On the action side, one may observe an **increase in both the probability and magnitude of extreme weather events,** such as heavy rainfall, snow, sea-level rise and hurricanes.
- Climate change may have an influence on the **return period of extreme events** (floods, extreme storm events, drought)
- The climate change effects resulting in extreme events warrant new **probabilistic models for design of resilient structures**



Example : Climate-dependent stochastic simulation framework for TC (Tropical cyclone) wind and rain hazards



Example : Probabilistic model of sea level rise



Example : Probabilistic model of Tsunami innundtation

Designing for replaceability during service

- Ganga bridge Patna is a classical case of doubling of CO2 footprint in in use stage.
- The bridge deteriorated within 20 years of construction and repaired number of times by external prestressing.
- Finally, the superstructure was replaced keeping substructure and foundation same.
- This also demonstrates the following cradle to crave sustainability characteristics of steel as a building material :
  - ✓Whole life impacts & benefits (Cradle to grave).
  - ✓Durability & Resilience.
  - ✓Flexibility and adaptability
  - ✓Versatility
  - ✓Reuse & Remanufacture
  - ✓Recycling

Structural systems for Carbon reduction in buildings

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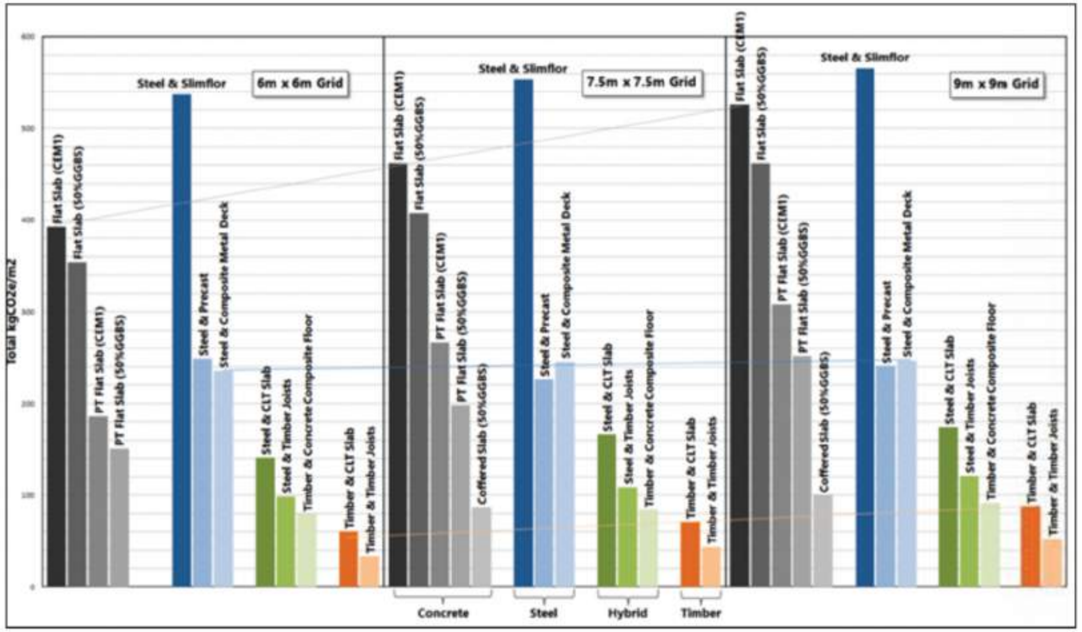
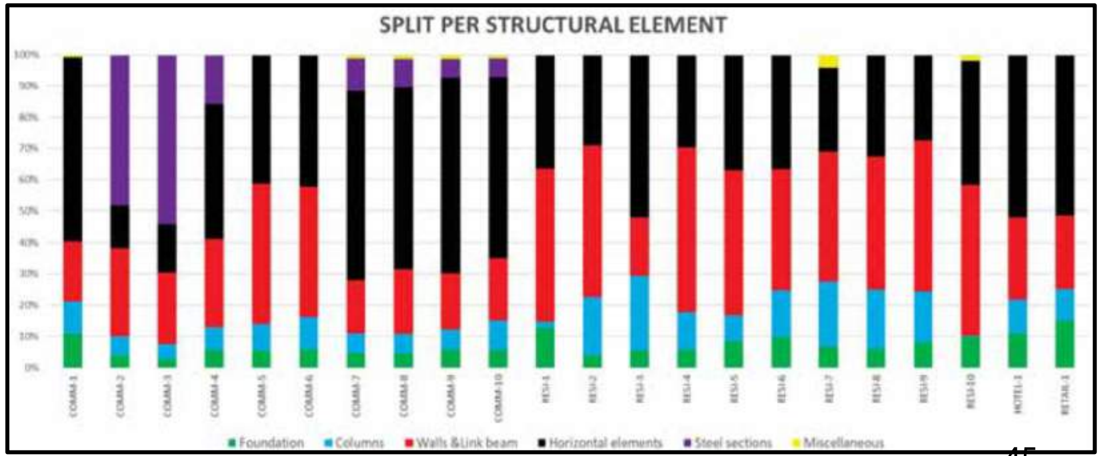
- Abhijeet Kulkarni, et al in their paper in SED journal reports the following on the basis of their study :
  - ✓Waffle slabs are more efficient RCC element for the slab while PT flat slab is also comparable.
  - ✓M40 grade concrete is most optimum.
  - ✓Higher grade of steel reduces the CO_2 emissions.
  - ✓GGBS content in the concrete can reduce emissions by 45%.
  - ✓PT slab can also reduce vertical height as such operational carbon requirement.
- **Present author's observation is that the foundations contribute less than 10% in building sector while infrastructure foundations are carbon intensive.**

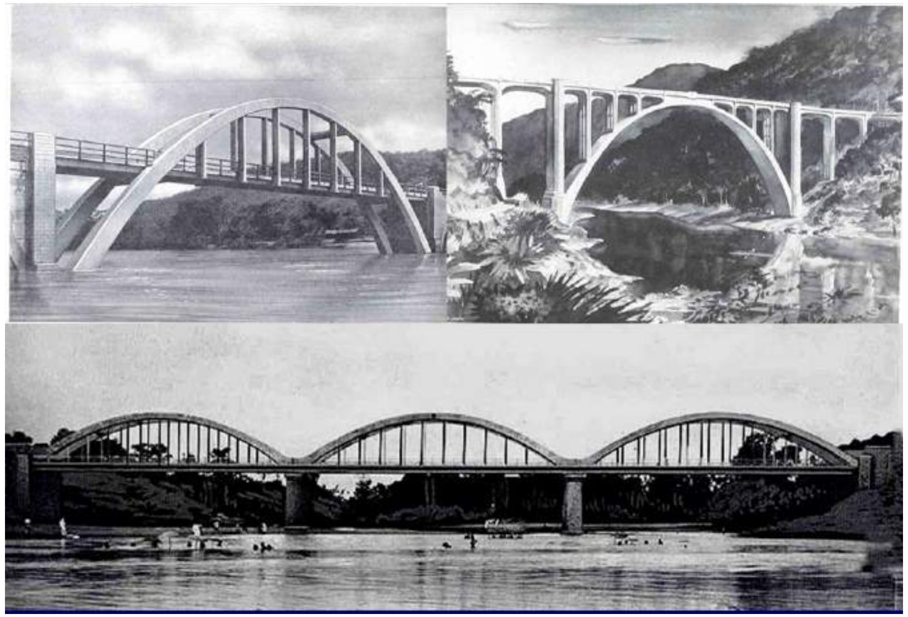


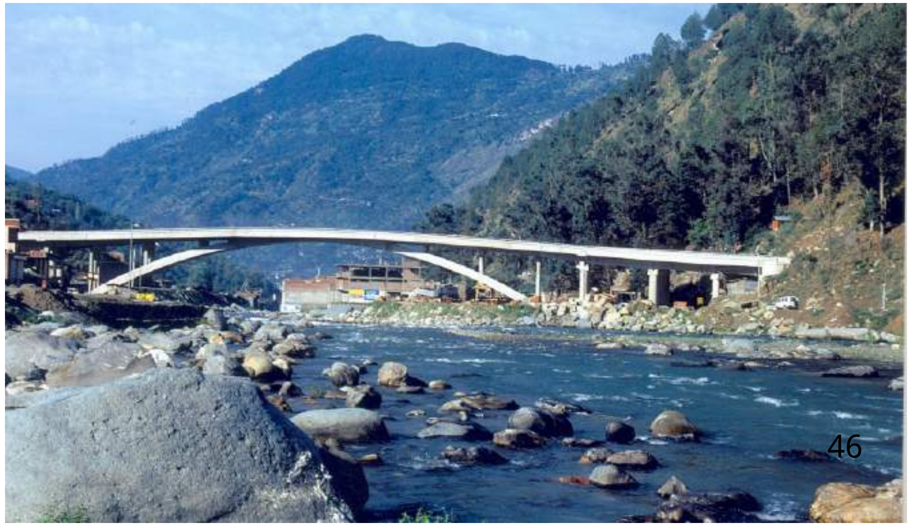


Source : Abhijeet Kulkarni, et al, Challenges and benchmarking of Embodied carbon of buildings in India, Structural Engineering Digest (SED), Vol.13, Issue 1, January-March 2023,pp 37-47.

Structural systems for concrete for sustainability

- **The structures with 'Form Following Forces'(F^3) like arch forms are time tested for its sustainability.**
- **These are the structures whose most of the components are subjected to maximum axial forces and minimum flexure.**
- **Since the arch forms are subjected to minimum flexure, less prone to cracking as such more durable from corrosion point of view.**
- **Even the expansion joints and bearings are minimum whose service life is normally much lesser than the structure life, requiring maintenance and replacement.**





Structural systems for sustainability

- **Pre stressing advantages in bridges:**
  - Lesser joints, bearings thereby minimal maintenance
  - Improved serviceability, durability. (Less deflection & Cracking)
  - Lesser cycle time during construction and minimum disruption of traffic.
  - Future pre stressing provisions.
  - Improved lighting visibility, leading to security and public safety
- **Pre stressing advantages in buildings:**
  - Thinner sections, large spans in beams and slabs reduces floor to floor height.
  - Minimum columns, flexibility in layout
  - Reduces steel & concrete by 20 to 30%.
  - Lesser façade area, lesser vertical systems like elevators, plumbing, electrical, HVAC
  - Reduced height leading to lesser energy consumption &reduced power for operating vertical systems during life currency

High Strength Composite Structural systems for decarbonization

- The choice of the structural system for any construction plays an important role in **reducing maintenance, transportation, material, energy usage, weight and improving fire resistance, noise reductions, indoor air quality and durability**.
- Some of the structural configurations like long standing arches have an inherent attribute of its **structural components being subjected to minimum flexure maximum axial forces** as such CFT are construction friendly and exploits the compressive strength of concrete .
- Also by virtue of its configuration does not warrant **expansion joints and bearings making the structures maintenance free**.

Structural systems for decarbonization

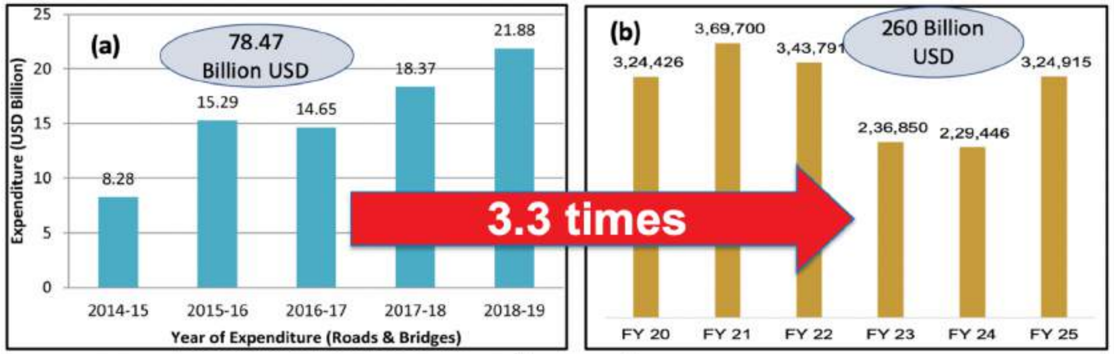
- **Ultra high-strength CFT columns & composite slabs offers many sustainable benefits in Buildings:**
  - ✓Thinner sections, large spans in beams and slabs **reduces floor to floor height.**
  - ✓Minimum columns, **flexibility in layout**
  - ✓Lesser **façade area**, lesser **vertical systems** like elevators, plumbing, electrical, HVAC
  - ✓Reduced height leading to **lesser energy consumption & reduced power** for operating vertical systems during life currency.
  - ✓Fast track construction.
  - ✓The combination of High **Strength Steel (780Mpa)** and **UHPC (150 Mpa)** is used for many towers in Japan.

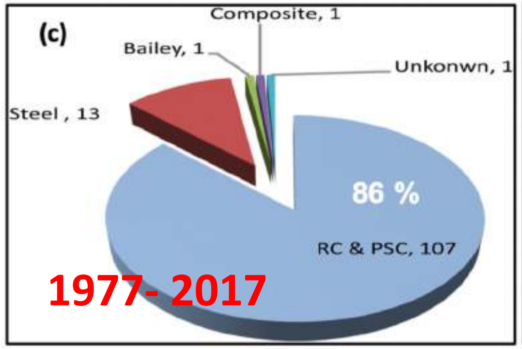
INDIA CHAPTER

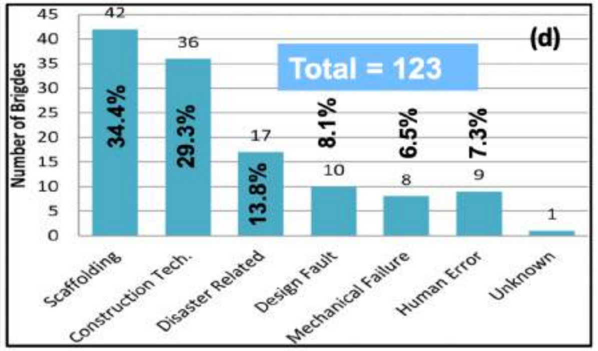
Structural safety and verifications

Design Engineering Construction
DECon Complete Solutions

Heggade on 'Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction'





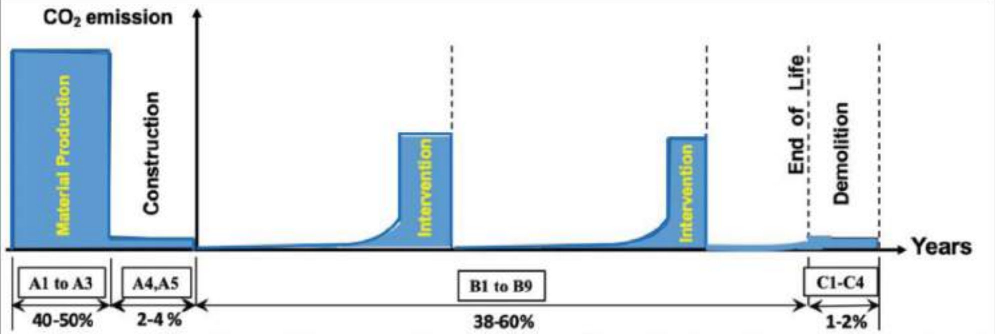


Reducing Carbon by upgradation of plants & re-formulation of ingredients at product stage

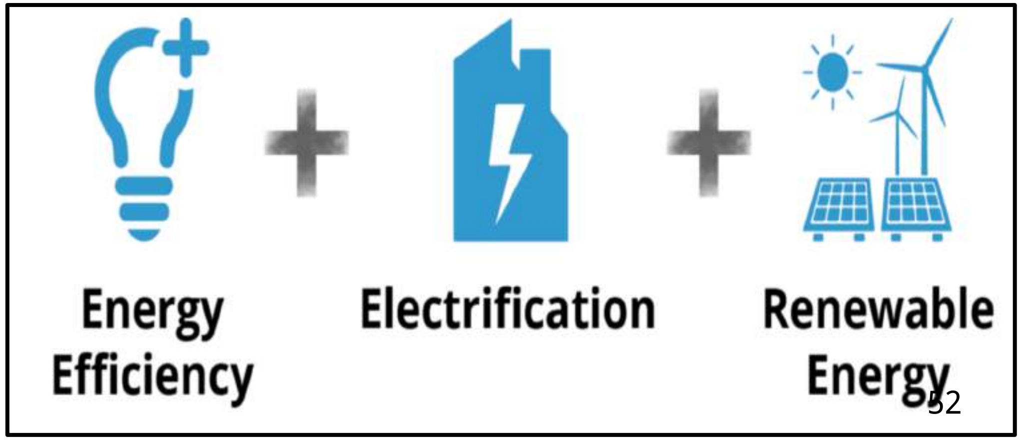
Decarbonizing Energy

Heggade on 'Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction'

- In the building sector 27% of operation carbon comes out operation energy of non-renewable fossil fuels having very high carbon factor.
- In infrastructure, almost same accounts for User Carbon.
- At the product stage, In the cement around 61 % EC is due to EE while in steel the same is around 72%.
- **Achieving zero emissions in built environment will require energy efficient buildings/infrastructure that use no on-site fossil fuels and are 100% powered by on- and/or off-site renewable energy.**
- These **Renewable Energy (RE)** sources are : ***Wind Energy, Solar Energy, Hydro electric energy, Bio mass energy and Nuclear Energy.***



	EC(t CO_{2eq})	EE(GJ)	CF of energy for (t CO_{2eq}/GJ)	EC_{EE} (t CO_{2eq}) (4)	EC_{DE} (t CO_{2eq}) (5)	EC_{PE} (t CO_{2eq}) (6)	CC (t CO_{2eq}) (4-6+5)	EC_{EE} Of CC	%age of EC_{EE} Of CC
Cement	0.8	5.5	0.197	1.084	0.48	0.32	1.244	0.764	61 %
Steel	2.5	30	0.197	5.91	2.25	0.25	7.91	5.70	72%



INDIA CHAPTER

Decarbonizing operation carbon in building sector

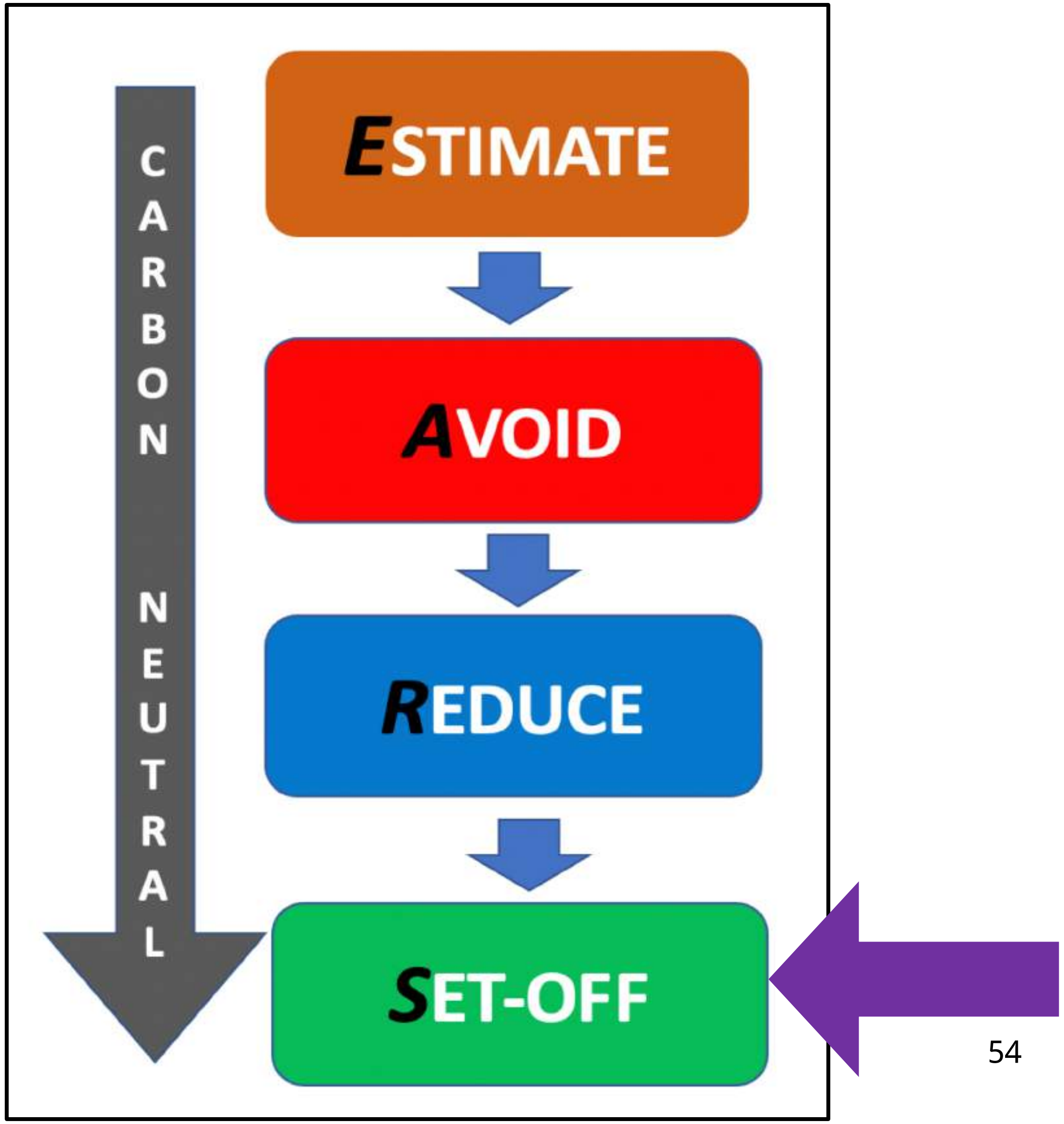
DECon Complete Solutions

- **Energy efficiency can be achieved** by using passive design strategies, such as natural ventilation, daylighting, shading, and insulation, as well as active systems, such as renewable energy sources, high-performance appliances, and smart controls.
- **Water efficiency can be achieved** by using low-flow fixtures, rainwater harvesting, greywater recycling, and water-efficient landscaping. By reducing the water consumption of buildings, green building certification can also reduce the energy required to pump, treat, and distribute water, which is another source of carbon emissions.
- **Indoor environmental quality can be influenced by** factors such as air quality, thermal comfort, lighting, acoustics, and ergonomics. Improve indoor environmental quality by using natural ventilation, low-emission materials, adequate insulation, daylighting, noise control, and ergonomic design. This can also reduce the carbon emissions associated with occupant behavior, such as adjusting thermostats, turning on lights, and using appliances

GREEN CERTIFICATION ACCOUNTS FOR ALL THE ABOVE

Setting off by Circularity

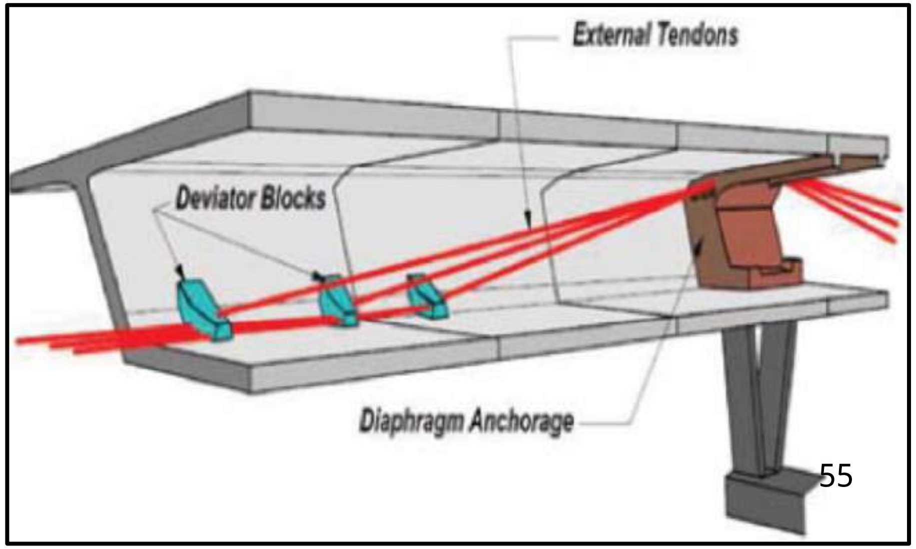
- The concrete structures have to be designed for :
  - ✓De-constructability
  - ✓Recyclability
  - ✓Reusability
  - ✓Recoverability
  - ✓Pro-longevity
  - ✓Scalability



Circularity by modular & pre-engineered Construction

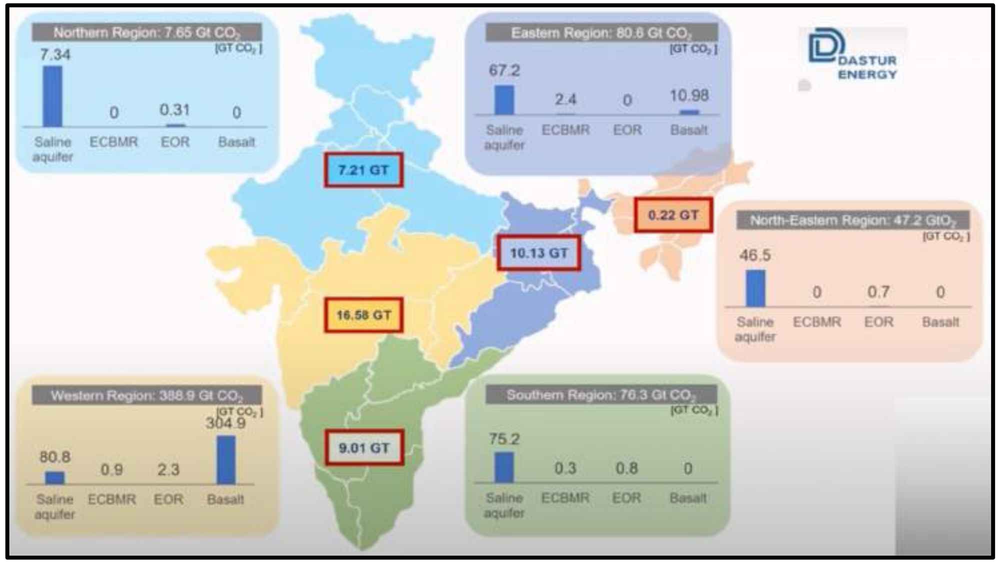
- Modular structures are those which are pre-engineered, prefabricated that are manufactured in a quality controlled factory and then shipped to site where they can be assembled and completed.
- **Shortened design and construction time is a major advantage.**
- Modular structures are simple to assemble, launch and dismantle for re-use.
- Similarly for Concrete bridges, the precast members can be designed in such a way that they can be dismantled and reused in new construction.
- The multi-cycle use of dismantled components by remanufacturing can bring the CO_2 emissions of A1 to A3 as close to zero as possible

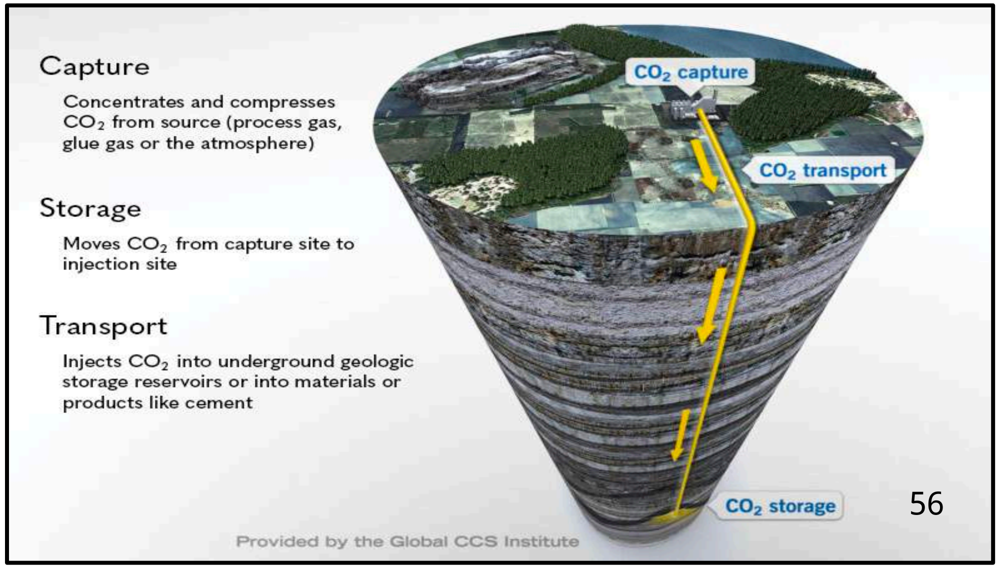
Source: https://letsbuild.com%



Setting off by 'Carbon Capture Utilisation & Storage' (CCUS)

- Decarbonizing fossil energy by renewable sources is a challenging task and it is expected that the same may happen to 50 % only by 2070.
- The balance decarbonization has to be achieved by **CCUS** alone.
- The **"Capturing"** technologies in India is in nascent stage and lot of R &D is on to reduce the cost.
- Under **"Utilisation",** in construction industry circular economy products could be ; **Curing, Aggregates, Carbon fiber, Polymers, Fuels – DME, SAF, Ethanol.**
- The majority has to be sunk by **"Storage"** in which India has the storing capacity of 600 GT mainly in **saline aquifers**.



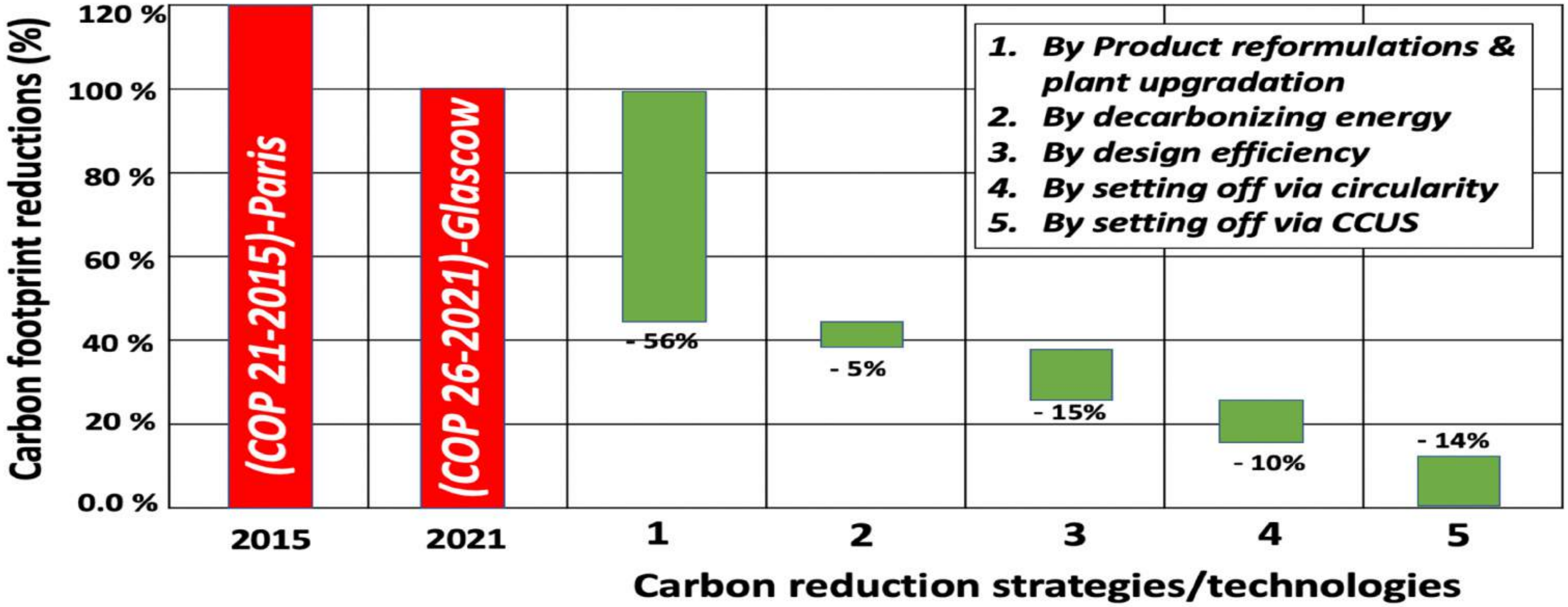


Roadmap to net zero carbon for concrete structures in built environment

Strategies for net zero carbon in cement

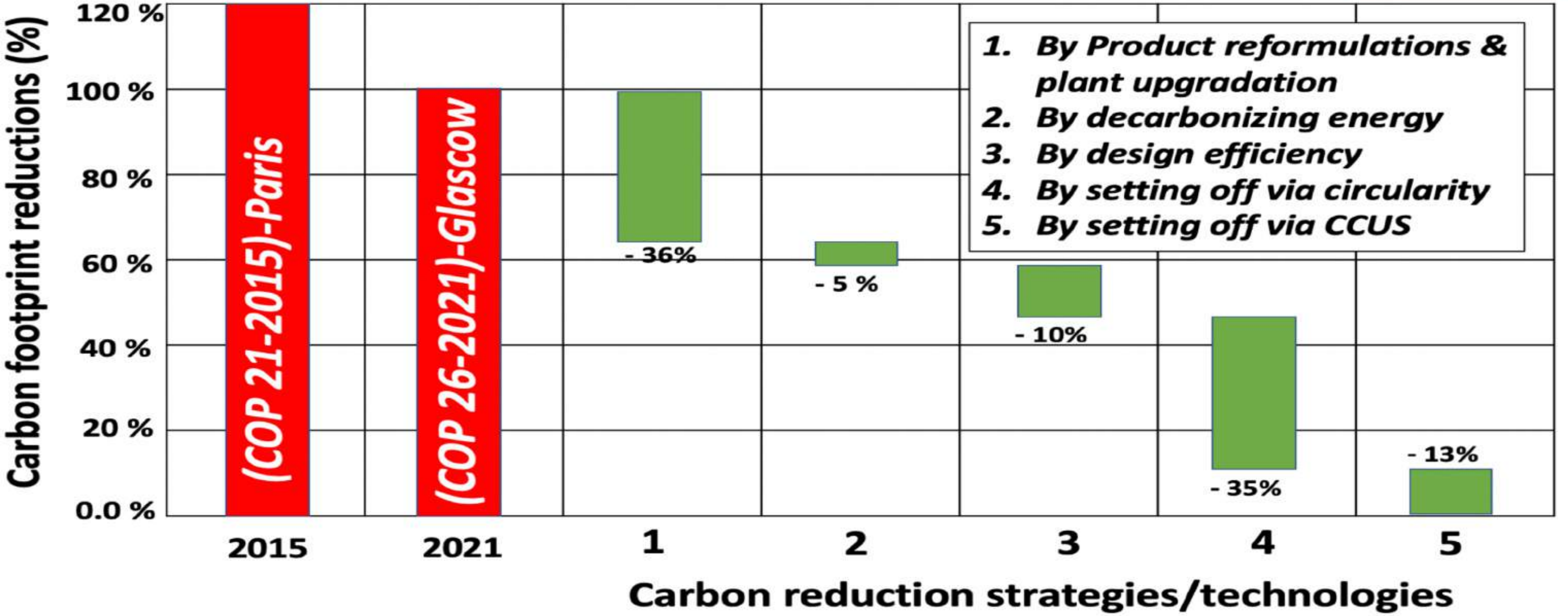
Heggade on 'Sustainable Development of Infrastructure Using Low Carbon Cement Concrete Construction'

S.N	Proposed Net zero strategies for cement	Carbon (%)	Reduction(%)	Bal (%)	Reduction (%)
1	By product reformulation & plant upgradation from 0.8 tCO_2 to 0.30 tCO_2 /t production (62.5%)	90	56	34	
2	Decarbonsing energy during production, construction & demolition by 50 %	10	5	5	
3	Design efficiency savings by 15%				15
4	Setting off by circularity				10
5	Setting off by CCUS				14



Strategies for net zero carbon in steel

S.N	Proposed Net zero strategies for Steel	Carbon (%)	Reduction(%)	Bal (%)	Reduction (%)
1	By product reformulation & plant upgradation in Steel from 2.50 tCO_2 to 1.50 tCO_2 /t production (40%)	90	36	53	
2	Decarbonsing energy during production, construction & demolition by 50 %	10	5	5	
3	Design efficiency savings by 10%				10
4	Setting off by circularity				35
5	Setting off by CCUS				13



Achieving net zero carbon in cement and steel is almost same as achieving net zero carbon in built environment

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