Lower Carbon Concrete: Market Drivers and Best Practices

WA ACI Chapter Meeting | April 21, 2021

Dave Walsh
Director of Sustainability | Sellen Construction

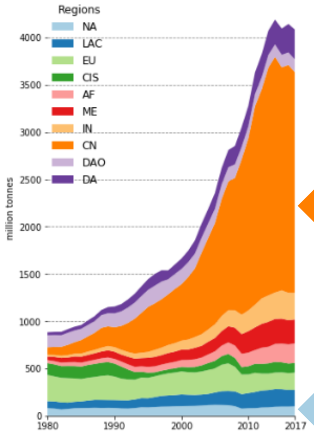
Image credit: Sellen

Materially Important:
concrete's essential role and unique ability to optimize

Concrete: Materially Important

- World's most common building material
- Ability for Architectural and Structural Expression
- Durability and Strength
- A Leader in Material Disclosure
- Key role in Infrastructure
- Exponential worldwide growth in use
- Ability to be carbon optimized

Worldwide Cement Use



Cement usage 1980-2017: a proxy for dramatic increase of concrete usage

China

North America

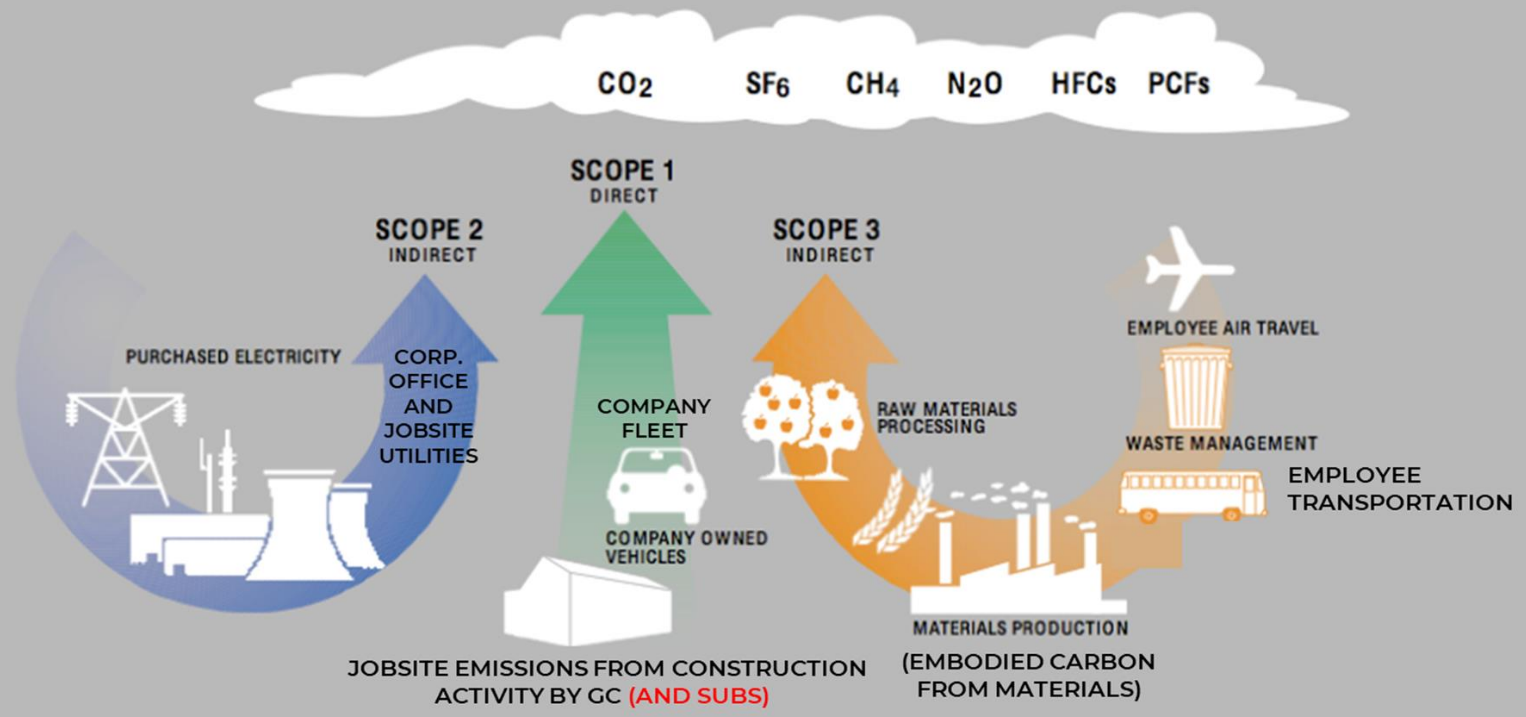
Source: Decarbonizing Concrete Report, March 2021

Image credit: bernerzeitung.ch

What:
Carbon, defined

"Carbon" = Greenhouse Gases

- **Carbon Dioxide (CO_2)**
  - Fossil Fuel Combustion
  - (Coal, Natural Gas, Gasoline, Diesel…)
  - Natural Sources
  - Process Emissions
- **Other Greenhouse Gases:**
  - **Methane (CH_4)**
    - Landfills
    - Agriculture
    - Natural Gas Systems
  - **Nitrous Oxides (N_2O)**
    - Car Emissions
    - Soils Management
    - Manufacturing
  - **Hydroflurocarbons (HFCs)**
    - Refrigerants
    - Manufacturing
  - **Perfluorocarbons (PFCs)**
    - Aluminum Production



Embodied Carbon	Emissions related to a material's lifecycle
Operational Carbon	Emissions from building operations

When:
Life Cycle Stages when carbon is emitted

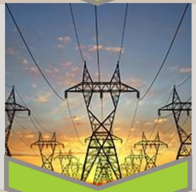
Embodied Carbon | A1 to A3

Product Manufacturing
Extraction/Harvest (Cradle) to Factory Gate

Embodied Carbon | A4 A5

Transport to Jobsite Construction Activity

Operational Carbon | B



Use Stage
Energy and Water Use

Embodied Carbon | C

End of Life Stage
Deconstruction/Demo/Disposal (Grave)

Embodied Carbon | D

Potential Recovery, Reuse or Recycle

How:
The opportunity to replace conventional cement

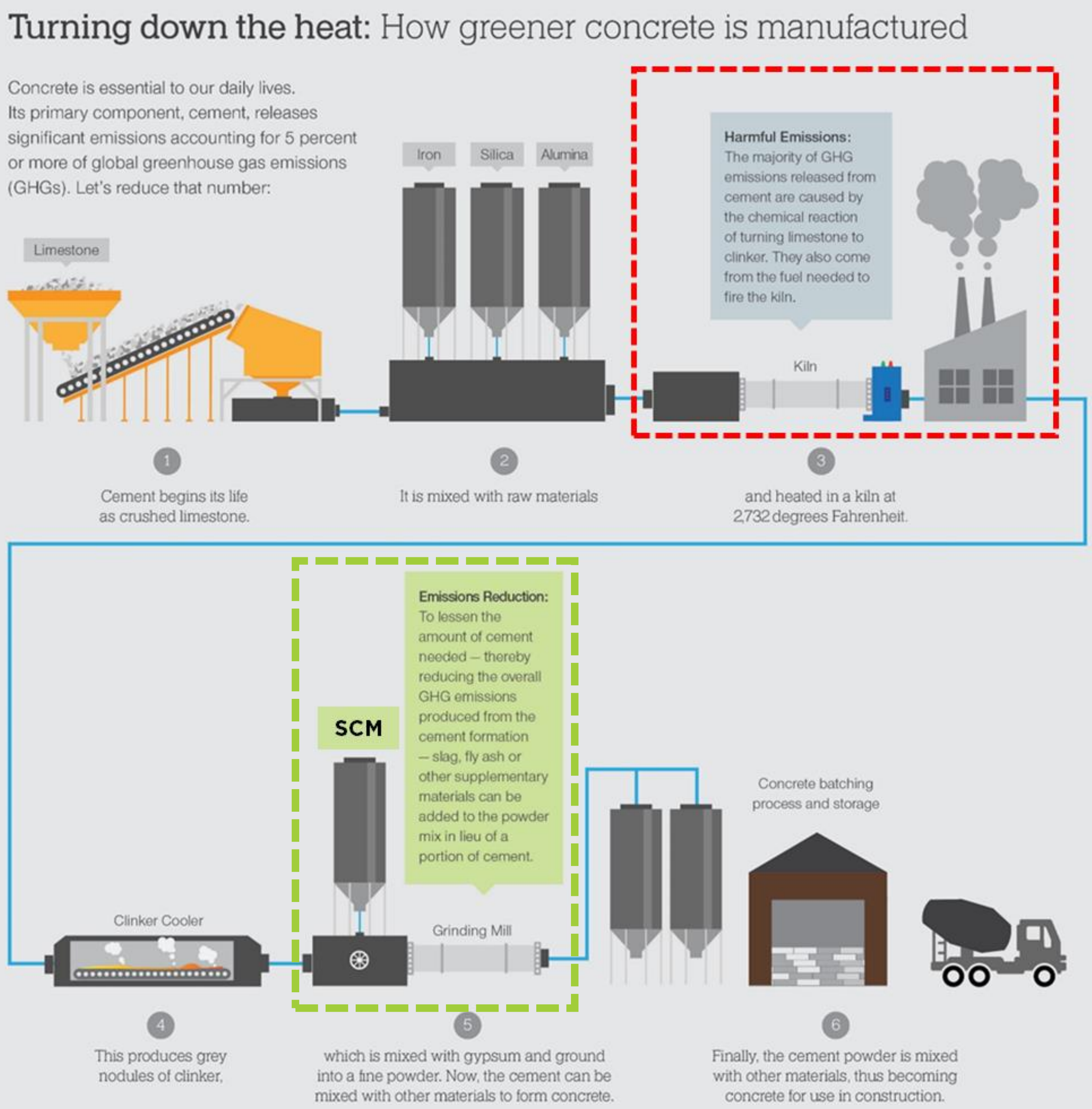
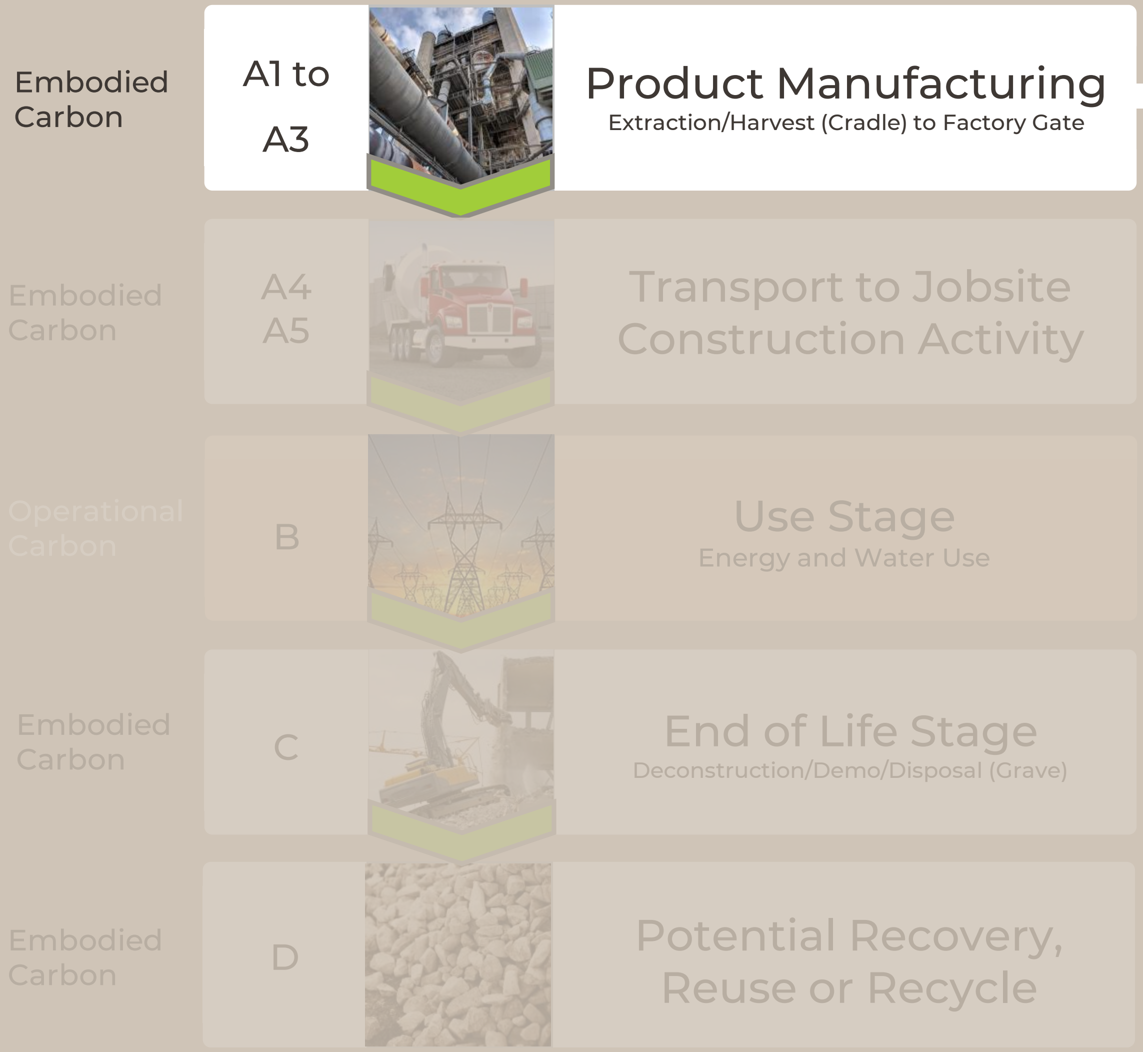


Image credit: Sellen

How:
GHG Reduction Opportunities: Manufacturing (and decisions prior manufacturing)



Strategies Prior to Manufacturing:

- Structural System Selection
- Informed Target Setting
- Material efficient design
- Performance Specs
- Informed Instructions to Bidders

Manufacturing Strategies

- Type 1L (PLC) Cement Use when allowed
- Supplementary Cementitious Material (SCM) Use
- Recycled Aggregate (RCA) Use when allowed

How:
GHG Reduction Opportunities: Transport and Construction Activity

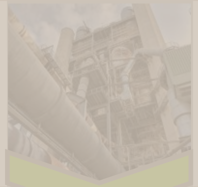
Embodied Carbon	A1 to A3		**Product Manufacturing** Extraction/Harvest (Cradle) to Factory Gate
Embodied Carbon	A4 A5		**Transport to Jobsite Construction Activity**
Operational Carbon	B		**Use Stage** Energy and Water Use
Embodied Carbon	C		**End of Life Stage** Deconstruction/Demo/Disposal (Grave)
Embodied Carbon	D		**Potential Recovery, Reuse or Recycle**

Transport and Construction Management Strategies:

- Reduction of Jobsite Wait Time
- Electronic Ticketing to validate Carbon Reduction Forecast
- Maturity Meters to confirm strength and fine tune mix selection avoiding unnecessary emissions

How:
GHG Reduction Opportunities: Future Reuse

Embodied Carbon | A1 to A3



Product Manufacturing
Extraction/Harvest (Cradle) to Factory Gate

Embodied Carbon | A4 A5

Transport to Jobsite Construction Activity

Operational Carbon | B

Use Stage
Energy and Water Use

Embodied Carbon | C

End of Life Stage
Deconstruction/Demo/Disposal (Grave)

Embodied Carbon | D

Potential Recovery, Reuse or Recycle

Recycle and Reuse Strategies:

- Design for Material Recovery
- Recycling of Demolished Materials
- Recycled Concrete Aggregate(RCA) Manufacturing
- RCA permitted in specs for next project

Market Drivers:

the increasing demand to measure and reduce carbon

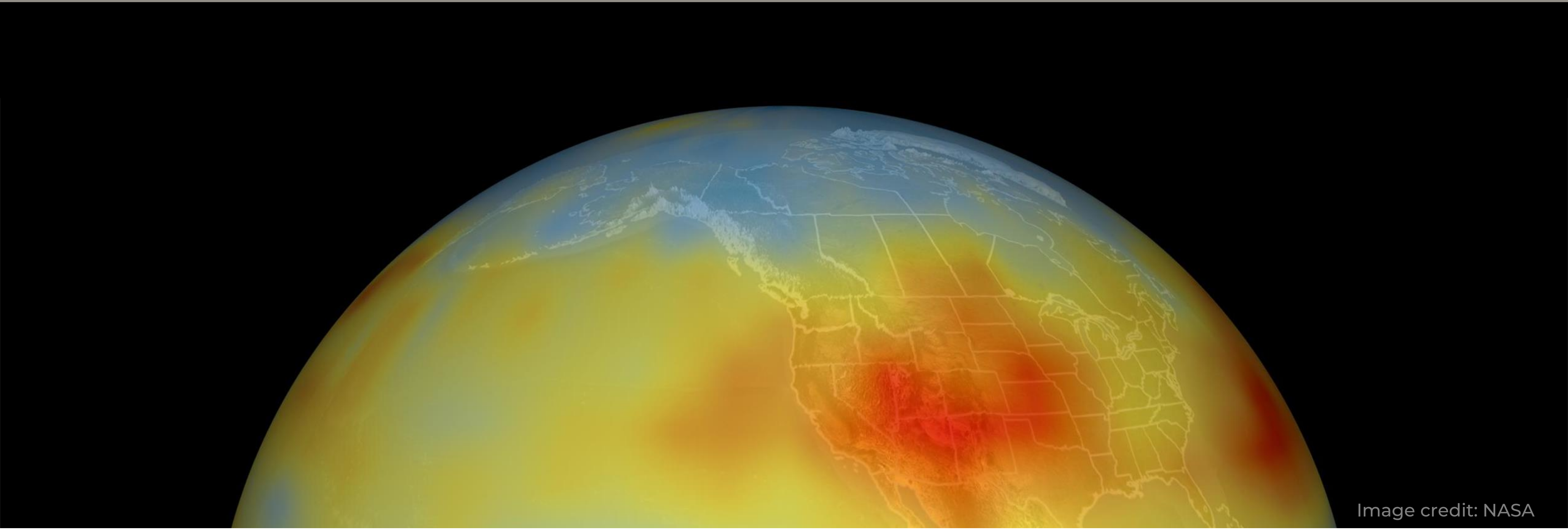


Image credit: NASA

Private Businesses, Public Commitments

Amazon's Climate Pledge

THE CLIMATE PLEDGE Paris... 10 years Early

Announced: September 19, 2019

Amazon:
Commits to net zero carbon by 2040 and 100% renewable energy by 2030

Microsoft:

- By 2030: Carbon negative,
- By 2050: MS will remove all carbon the company has emitted since 1975
- Zero Carbon Certification for Project

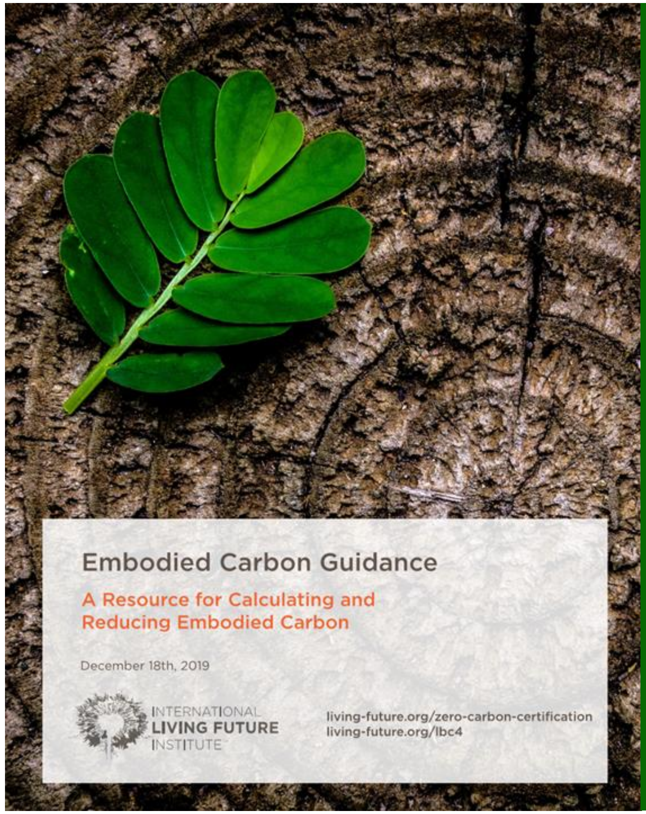
Microsoft's Climate Commitment

Announced: January 13, 2020

Embodied Carbon in Sustainability Certifications

Zero Carbon Certification

International Living Future Institute



Lower Carbon Materials:

- The embodied carbon emissions impact of the primary materials of the foundation, structure, and enclosure have been reduced by a minimum of 10%, compared to baseline scenario
- The total embodied carbon emissions of the project must not exceed 500 kg-CO_2e/m^2 (for the covered categories)

LEED v4.0/v4.1

Building Life-Cycle Impact Reduction
Credit MRc1

Procurement of Low Carbon Construction Materials
Pilot Credit MRpc132

Available Embodied Carbon Software Tools

Athena Impact Estimator

Confirming early design decisions

Good For:

- Early Concept
- No Drawings, just quantities
- Early Structural Systems Options
  It's easy to use
- It's Free!

Limitations:

- Limited Database of Materials
- No ability to fine-tune with specified EPDs
- Doesn't cover all categories

Tally

Holistic understanding of design decisions

Good For:

- Entire project phases: concept to final design
- Extensive Database – can fill the gaps where no EPD exists
- Can update GHG values with specific EPDs in post-processing

Limitations:

- Requires somewhat granular BIM Modeling
- Hard to accommodate multiple BIM models from different design teams
- Requires some training to use
- Cost

EC3

Product selection and procurement decisions

Good For:

- Entire project phases: concept to final design
- Easy to use – BOM data entry
- Understand how a specific product compares with baselines
- It's Free!

Limitations:

- Database is growing, but gaps exist
- Includes just A1-A3 impacts for GHG
- Apples-to-apples comparisons sometimes not possible
- Cost

The Trend Line is Clear

Annual GHG Readings – Mauna Loa Observatory, Big Island

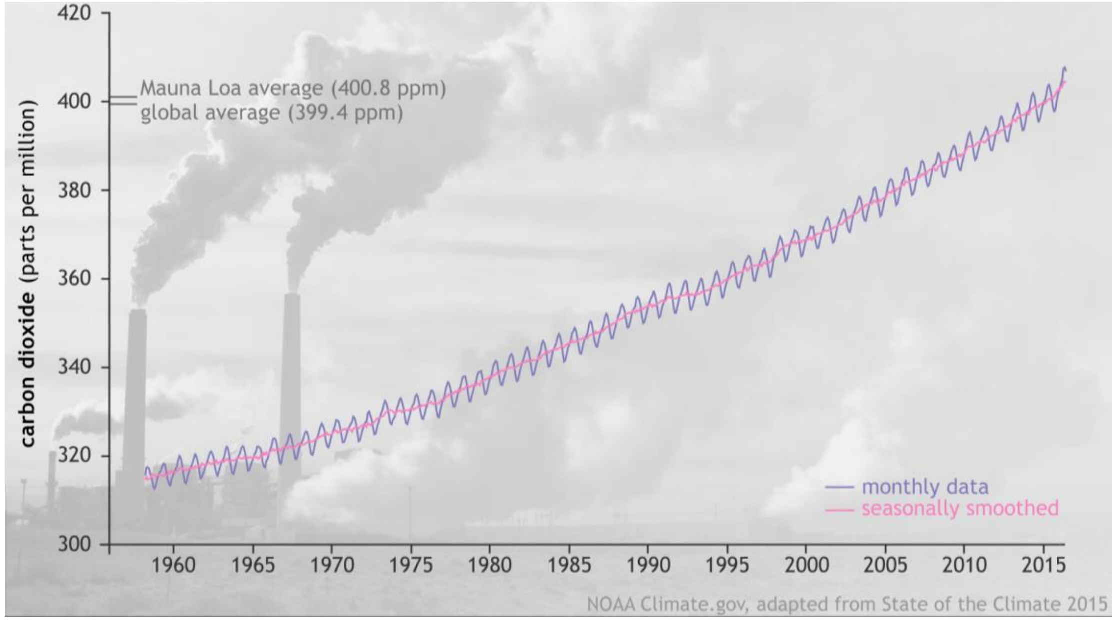
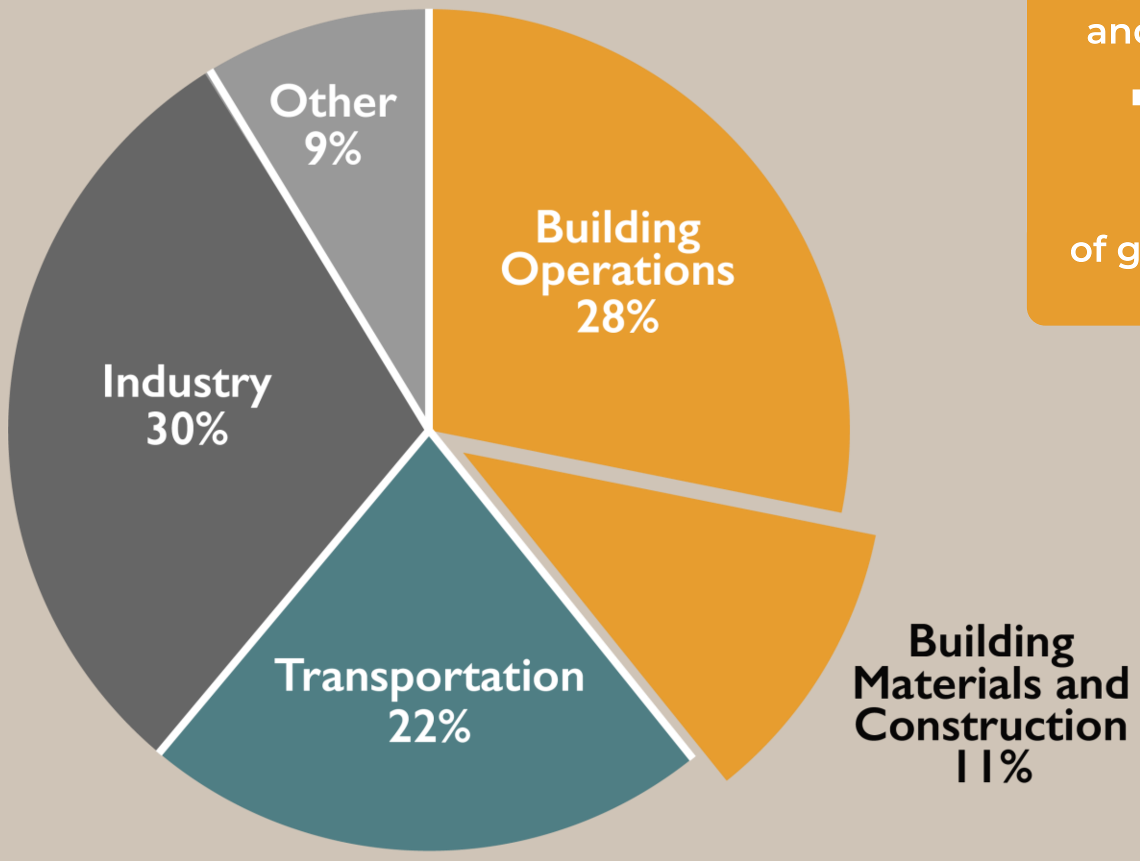


Image credit: Dave Walsh

Building Materials Play a Significant Role in Total Greenhouse Gas Emissions

Annual Global CO_2 Emissions



Building Materials and Construction

11%

of global emissions

Source: UN Environment Global Status Report 2017
Data Source: IEA (2017), World Energy Statistics and Balances

Image Credit: Architecture 2030

Embodied Carbon vs Operational Carbon

Over a 30 Year Period – Business as Usual Building Efficiency

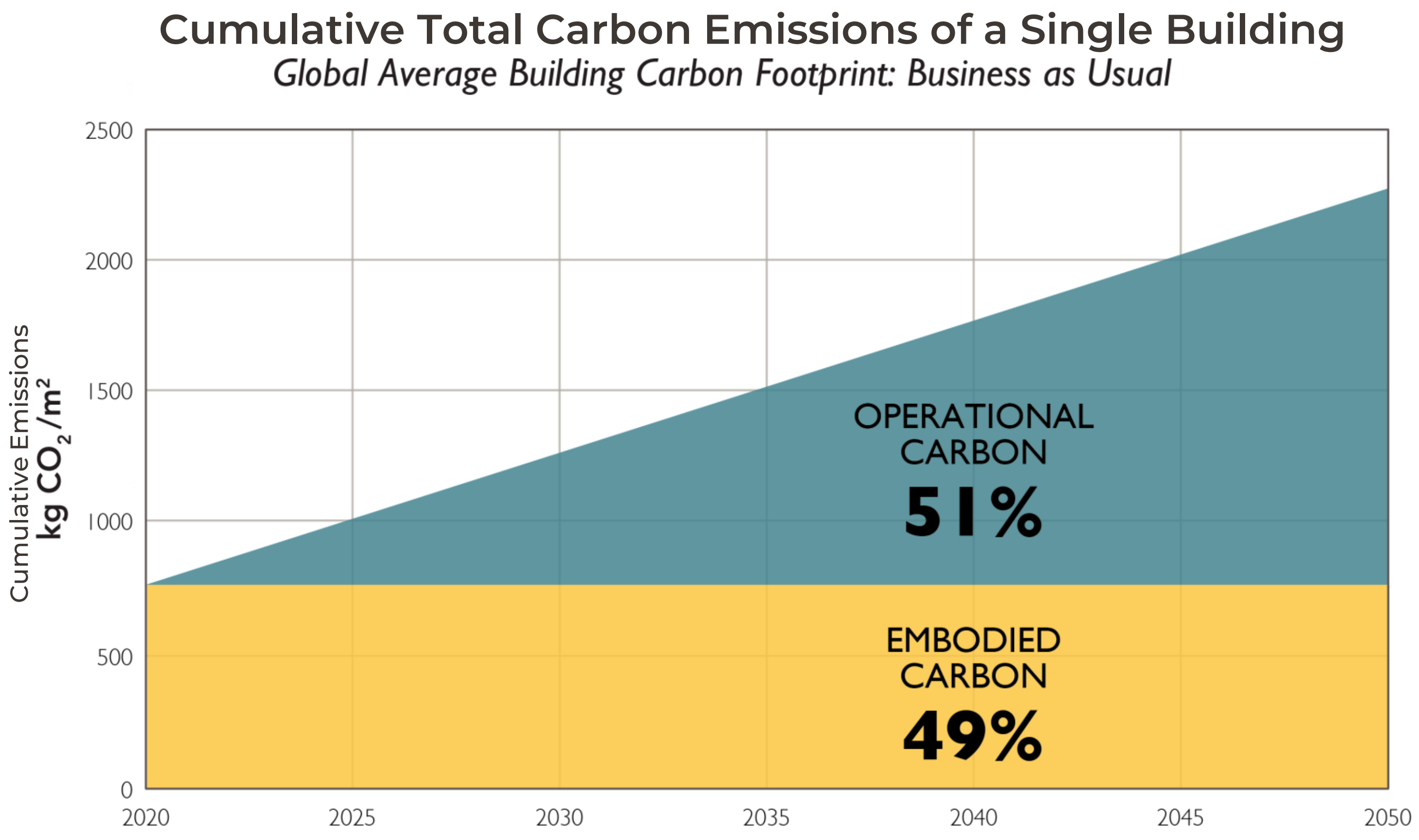


Image Credit: Architecture 2030

Embodied Carbon vs Operational Carbon

Over a 30 Year Period – Energy Efficient Buildings

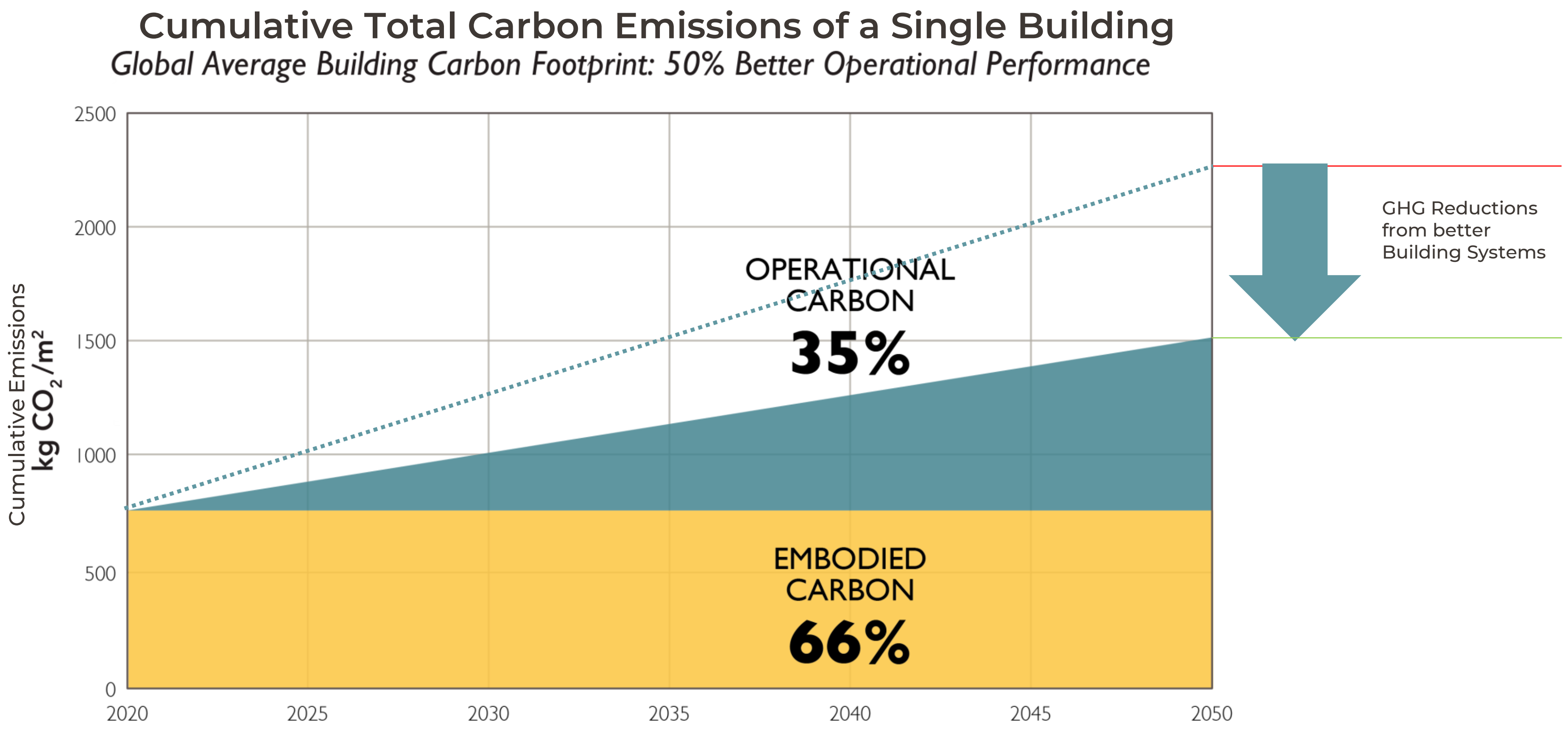


Image Credit: Architecture 2030

Embodied Carbon vs Operational Carbon

By the Critical Date of 3020: Embodied Carbon is the Urgent Concern

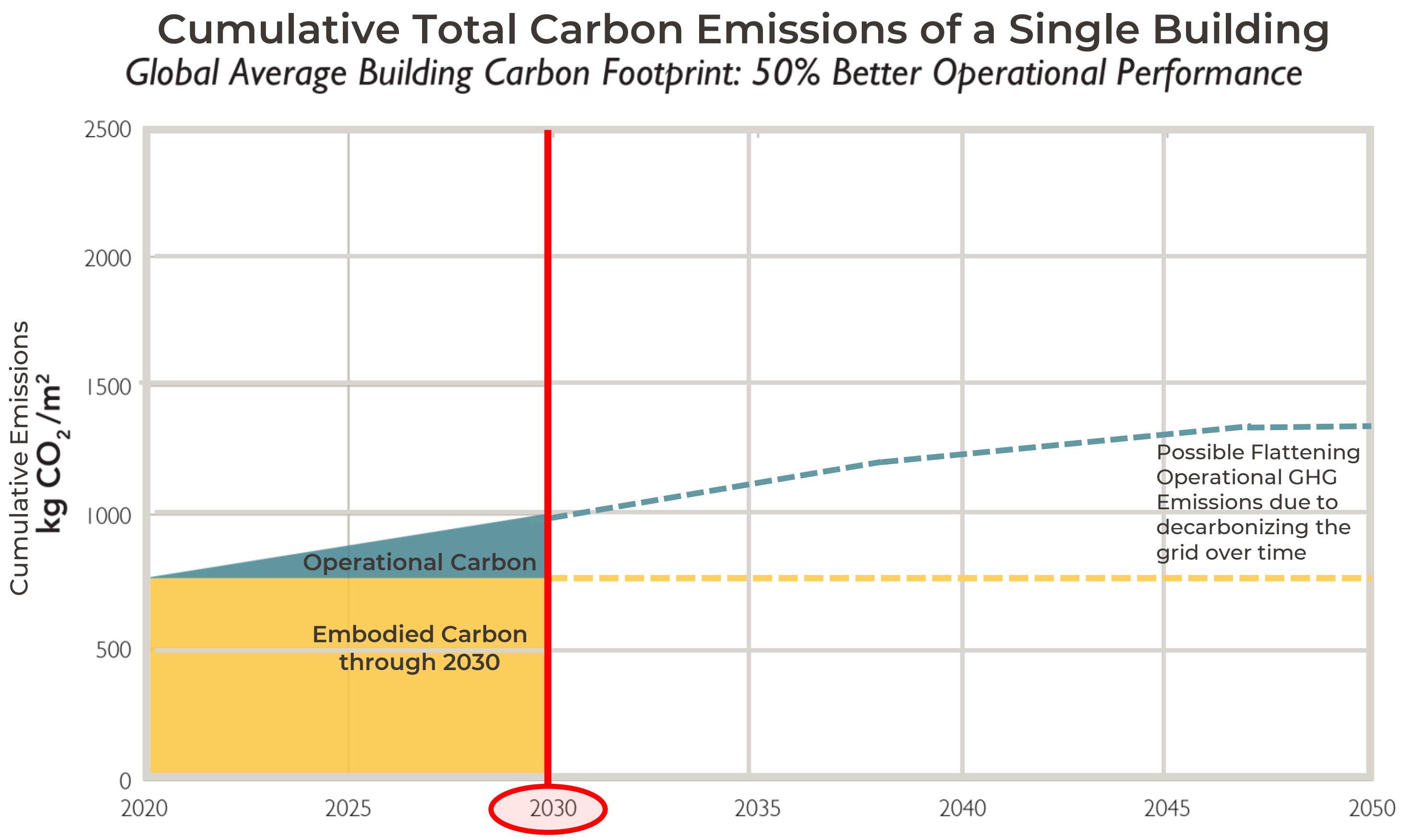


Image Credit: Architecture 2030

Legislation on the Horizon:
carbon disclosure of structural materials is coming

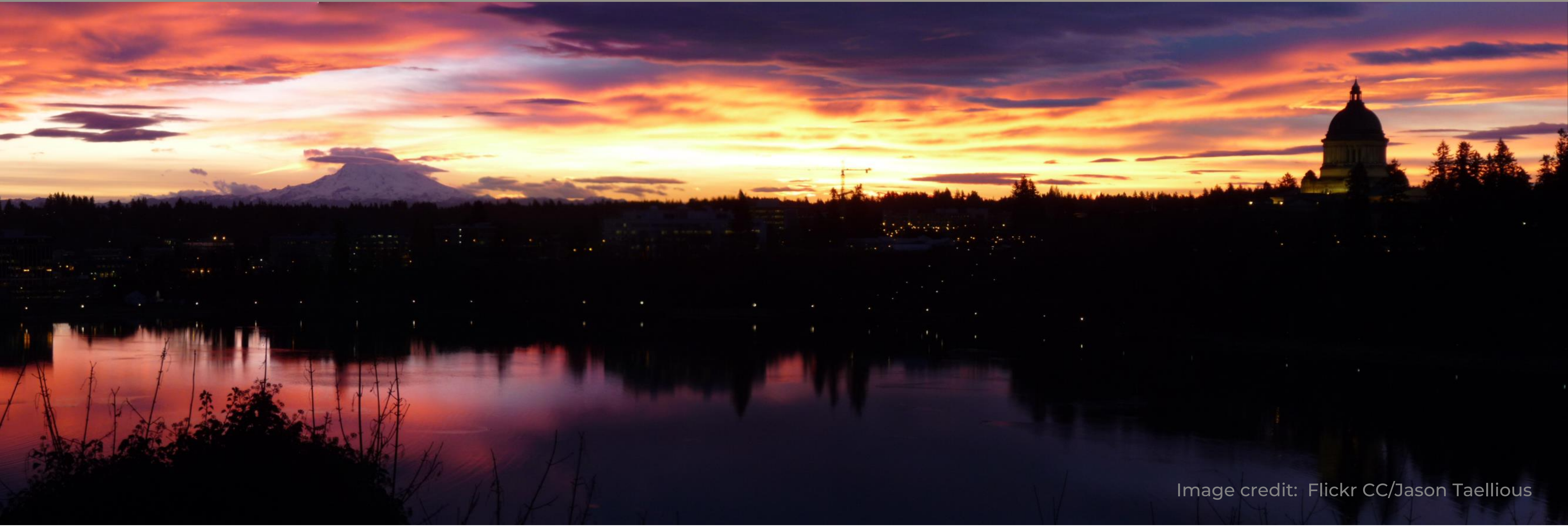


Image credit: Flickr CC/Jason Taellious

State of Embodied Carbon Legislation in the USA

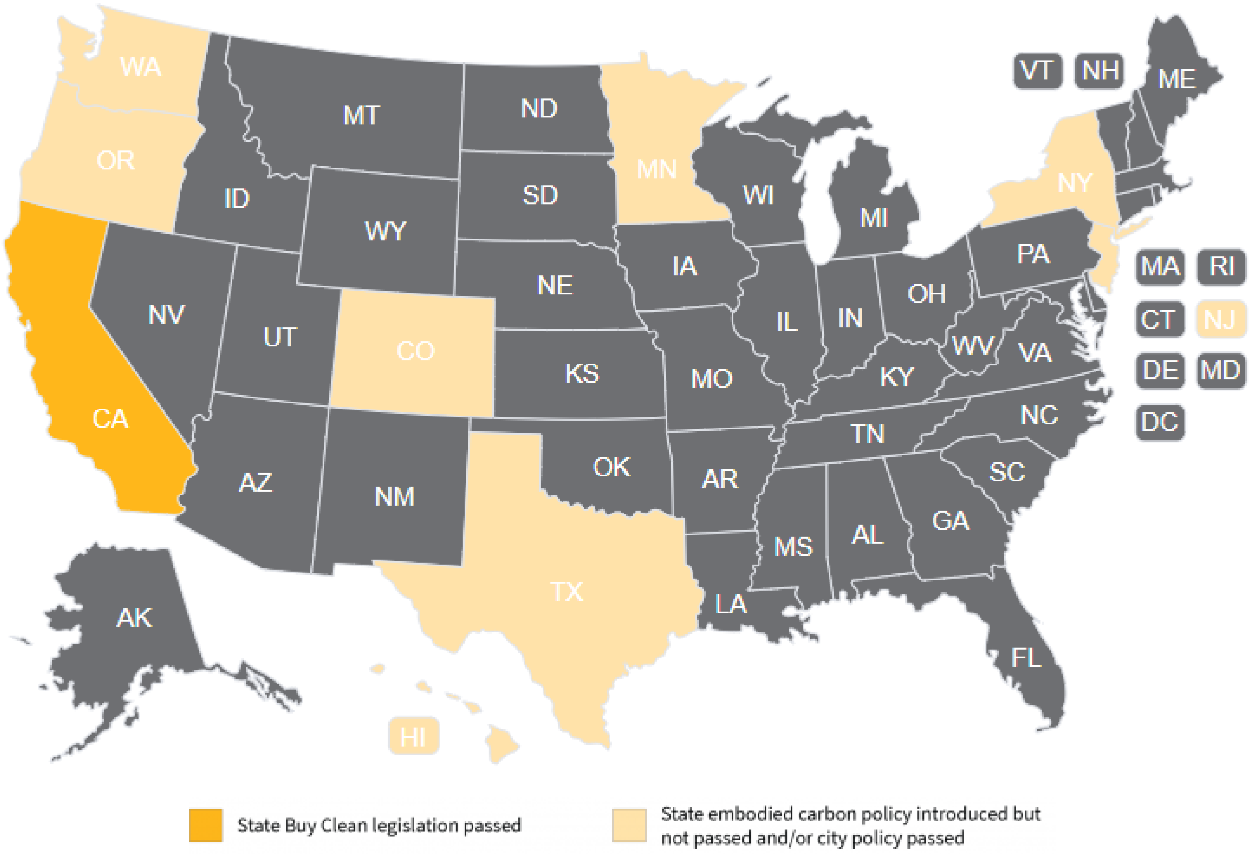


Image credit: Carbon Leadership Forum

- Adopted or Pending Legislation in 9 States
- Action happening at the State, County and City levels
- Most, but not all affect concrete disclosure
- Legislation generally falls into two categories:
  - Track and disclose embodied carbon using third-party verified mix specific EPDs
  - Track, disclose and emit less than a legislated emissions cap
- Applicability varies: from pilots impacting a few projects to all public and private projects

Embodied Carbon Legislation/Public Policy Overview affecting Concrete

does not include: private owner initiatives/policy or public policy under consideration but not yet introduced or implemented. Data as of 4/19/21

Type of Legislation Impacting Concrete

	EPDs and Embodied Carbon Disclosure Required		EPDs +Disclosure Required + Max GHG Cap or Cap Phase-in Required	
Applies to all Projects	WA – City of Seattle Expedited Permitting for EPDs		CA – Marin County Low Carbon Concrete Code	
Applied to Publicly Funded Projects	WA – HB 2608 Buy Clean Buy Fair WA	MN – B3 Requirements LCA Modeling and EPDs	OR – City of Portland Rqmts for Approved Mixes	CO – SB 159 (2020) GWP for Public Project Matls
	OR – HB 2608 EPDs and Enviro. Cost	NJ – Assembly Bill 5253 Low EC Conc. Tax Credits`	CA – AB 1365 Public Contracts Clean Conc.	CA – AB 1369 Expands Buy Clean CA to Conc
	NY – SB S542 Low EC Conc. Leadership Act`		USA – CLEAN Future Act Federal Buy Clean Program	
Pilot: Limited Projects	WA – Sound Transit EPDs on Select Projects	OR – HB 2688 ODOT and required EPDs		
	CA – Caltrans EPDs on Select Projects	NY NJ – Port Authority of NY & NJ Clean Construction Program		

Legislation Key: Green: Legislation Passed & Law | Gray: Legislation Introduced

Image credit: Sellen

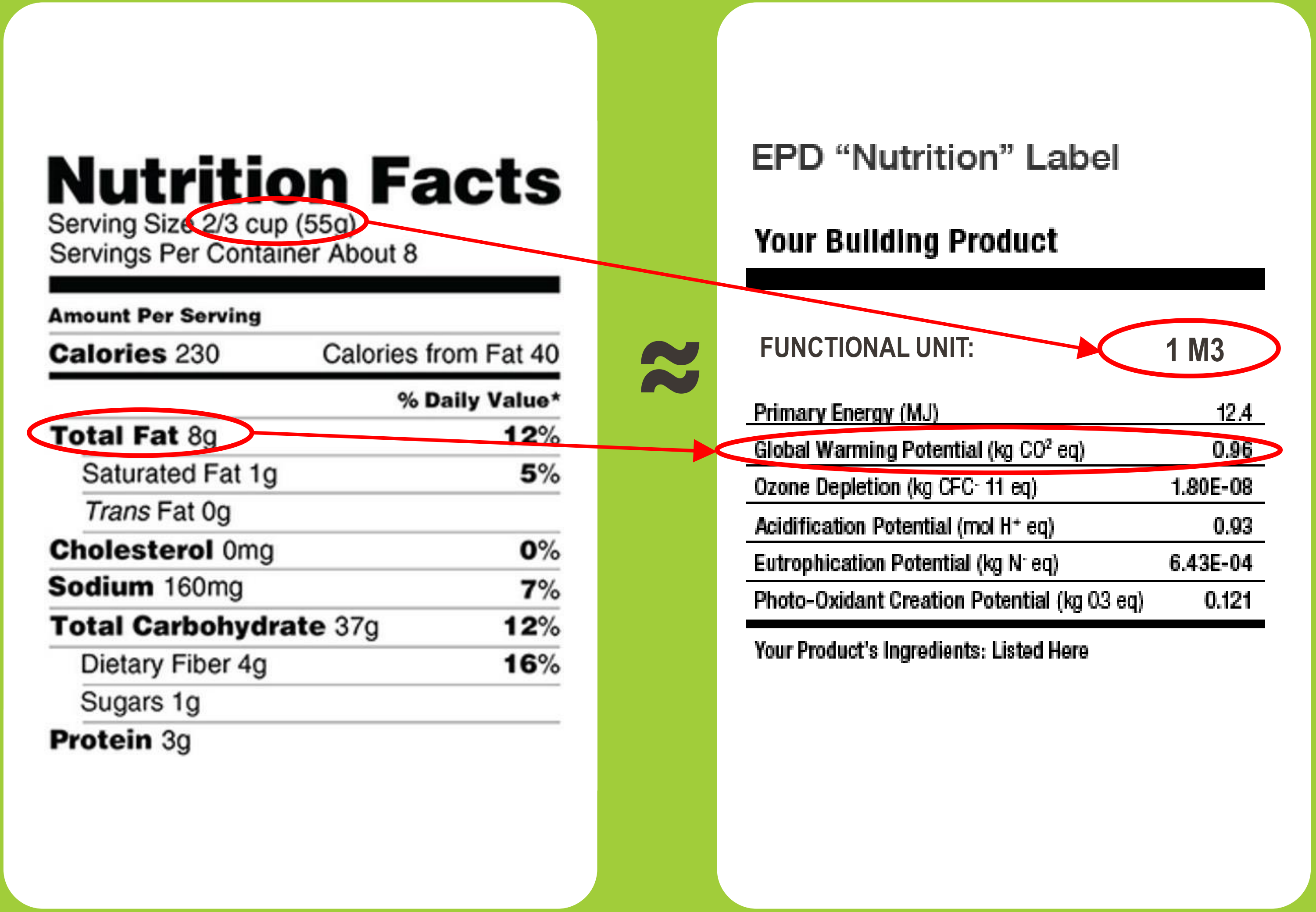
Baseline and Targets:

measuring GHG and different approaches to setting reduction goals

Image credit:
Flickr CC/Lynn Friedman

EPD: Environmental Product Declaration

the "food label" of material impacts



EPDs can be:

- Industry-wide average
  or
- **Product-specific (for a specific mix from a specific plant)**

  and

- **Third-party reviewed (meeting ISO guidelines)**
  or
- Not third-party reviewed

Select your Baseline

"Lower Carbon Concrete" starts with defining a Baseline

Option 1: NRMCA (National Ready Mix Concrete Association) Baseline, 2016

- Widely used reference and widely understood
- Has both National and Regional Data
- Is not application specific, so not always a fair comparison
- Does not include strengths above 8000 psi

Option 2: Carbon Leadership Forum, 2019 (updated 2021)

- Published, November 2019
- Has published low, average and high baselines, be clear which to use
- Works with EC3
- No regional averages

Athena Sustainable Materials Institute

www.athenasmi.org

NRMCA Member National and Regional Life Cycle Assessment Benchmark (Industry Average) Report – Version 2.0

Prepared for: National Ready Mixed Concret

Prepared by: The Athena Sustainable Mater

October 2016

NRMCA NATIONAL READY MIXED CONCRETE ASSOCIATION

Table E5-Pacific Northwest LCA Results

Indicator/LCI Metric	Unit (equivalent)	GWP kg CO2
2500 psi	per yd3	204.00
	per m3	266.82
3000 psi	per yd3	227.91
	per m3	298.10
4000 psi	per yd3	280.38
	per m3	366.73
5000 psi	per yd3	348.27
	per m3	455.53
6000 psi	per yd3	367.01
	per m3	480.03
8000 psi	per yd3	449.58
	per m3	588.03
3000 psi Lightweight	per yd3	386.66
	per m3	505.73
4000 psi Lightweight	per yd3	444.90
	per m3	581.91
5000 psi Lightweight	per yd3	509.38
	per m3	666.24

Image Credit : NRMCA

CLF Carbon Leadership Forum

		Low	Avg.	High	Declared unit
Ready Mixed Concrete	2500psi	230	290	380	m3
	3000psi	260	320	420	m3
	4000psi	310	390	520	m3
	5000psi	380	490	640	m3
	6000psi	400	510	670	m3
	8000psi	470	620	790	m3

Image Credit: CLF

Select your Baseline

Option 3: Custom Baseline from Project-specific Historical Data

- Requires data collection from past applicable projects
- May need to be adjusted for newer cement used
- Can inform a real-world business-as-usual (BAU) baseline
- Is very location specific and very application specific – good for repetitive projects

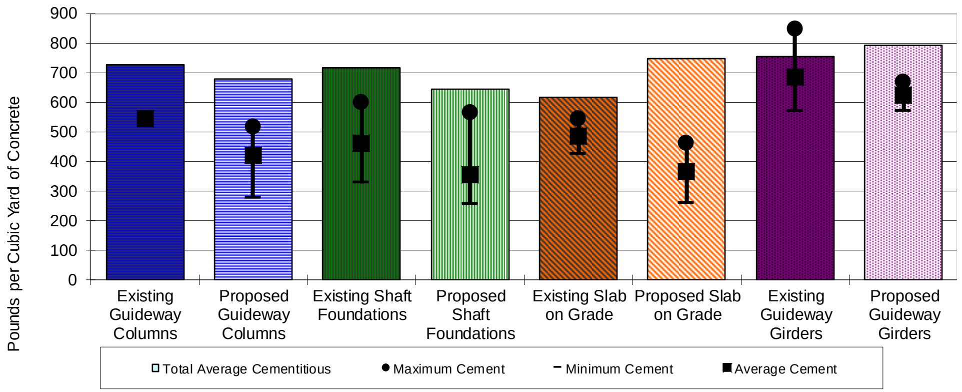


Image Credit: KPFF / Sellen

Image Credit: Sound Transit

Set the Reduction Goal

Option 1. Project-wide Reduction Requirement

- Requirement is a single percentage reduction
- A weighted average for all the concrete
- Each mix is compared to the corresponding baseline for its strength
- Simple to specify but hard to get set goal right
- Allows flexibility for how much each application must reduce
- What's BAU and what's ambitious depends on the proportion and types of uses in the project.

Example Calculation

Reduction multiplied by % Vol. = Weighted Reduction

Application (Use)		Percent Below NRMCA 2016	CY in Est	% by Vol.	Weighted % below NRMCA
Drilled Shafts, 4k	Mix # *********	19.56%	44	0.3%	0.1%
SOG, 4k, F0	Mix # *********	35.92%		0.0%	0.0%
Foundation, 4k, F0	Mix # *********	35.92%	1,024	7.6%	2.7%
SOG, 4k, F1	Mix # *********	29.38%	7	0.1%	0.0%
Foundation, 4k, F1	Mix # *********	29.38%	1,769	13.1%	3.8%
Curbs/Pads/Retaining Walls, 4.5k, F2	Mix # *********	33.35%	721	5.3%	1.8%
Basement Walls and Basement Foundations, 5k	Mix # *********	39.63%		0.0%	0.0%
Mild & PT Slabs/Beams, 6k	Mix # *********	42.09%	6,243	46.2%	19.5%
Columns/Shear Walls/Basement Walls, 6k	Mix # *********	43.13%	1,620	12.0%	5.2%
Shotcrete--Tunnel and Basement Walls , 6k	Mix # *********	18.34%	555	4.1%	0.8%
Shear Wall/Columns, SCC, 8k	Mix # *********	48.81%	1,523	11.3%	5.5%
Shear Wall/Columns, SCC, 10k	Mix # *********	43.20%		0.0%	0.0%
			13,506		39.3%

Repeat for each mix and sum for project reduction

Goal is 30%

Example Specification Language
For a project-wide reduction requirement

Provide concrete mixes such that the percent reduction in weighted average Proposed Mix GWP as compared to the weighted average Benchmark GWP shall be a minimum of 30%.

Calculate the weighted average Benchmark GWP for the volume of concrete corresponding to the Proposed Mix Designs with EPDs as follows:

$$GWP_{AVG\ BENCHMARK} = \frac{\sum_{i=1}^{n}[GWP_{i\ BENCHMARK} \times Volume_i]}{\sum_{i=1}^{n} Volume_i}$$

Where:
$GWP_{i\ BENCHMARK}$ = benchmark global warming potential for concrete class i
$Volume_i$ = volume of concrete for concrete class i
n = total number of classes of concrete

Calculate the weighted average Proposed Mix GWP as follows:

$$GWP_{AVG\ PROPOSED} = \frac{\sum_{i=1}^{n}[GWP_{i\ PROPOSED} \times Volume_i]}{\sum_{i=1}^{n} Volume_i}$$

Where:
$GWP_{i\ PROPOSED}$ = global warming potential for proposed mix i
$Volume_i$ = volume of concrete for proposed mix i
n = total number of proposed mixes of concrete

Calculate the percent reduction in weighted average Proposed Mix GWP as compared to the weighted average Benchmark GWP as follows:

$$\%\ Reduction = \frac{GWP_{AVG\ BASELINE} - GWP_{AVG\ PROPOSED}}{GWP_{AVG\ BASELINE}} \times 100$$

Specification Credit: KPFF Engineers

Set the Reduction Goal

Option 2: Required Reductions for each Application

- Requires a minimum reduction or required reduction ranges specific to each application
- Requires a good knowledge of what's possible for each application
- Does not allow flexibility for the supplier and contractor

Focus reduction effort on the applications (uses) with the highest volumes

The required design strength determines which NRMCA baseline is used

Research similar projects with the same application, strength to set min. reduction

Consider setting a stretch goal for each application. Be realistic for each condition

f'c (psi)	Test Age (days)	APPLICATION	Priority for Targeting Reductions	cy	Percent of Conc	2016 PNW NRMCA Baseline (kg/m3)	Compressive Strength Used for Baseline	Required Min. Goal	Required Min. Target (kg/m3)	Stretch Goal	Stretch Target (kg/m3)
5000	28	Basement Walls	Low	505	0.8%	455.53	5000	0%	455.53	-10%	409.98
6000/8000	56	Columns	Medium	530	0.9%	480.03	6000	-35%	312.02	-50%	240.02
4000	56	Conc on Stl Deck	Low	15	0.0%	366.73	4000	-35%	238.37	-40%	220.04
4500	28	Curbs, pads	Low	0	0.0%	411.13	4500	-35%	267.23	-50%	205.57
4000	28	Foundations (Footings, grade beams, mat foundations, pits)	High	3055	5.0%	366.73	4000	-45%	201.70	-70%	110.02
6000	56	Mild slabs	Medium	365	0.6%	480.08	6000	-40%	288.05	-55%	216.04
6000	56	PT slabs	High	4405	7.1%	480.08	6000	-28%	345.66	-40%	288.05

Set the Reduction Goal

Option 3: An “Open Ended “ Reduction Requirement

- You (the supplier) tell us what the maximum reduction is
- Requires giving enough performance based with over encumbering with constraints
- Requires active participation of General Contractor to provide constructability and schedule information
- Requires trusted and experience partners

With the criteria provided… recommend the supplier’s most carbon-efficient mix for each application

Design Team Criteria
(for each application)

- Min. Design Strength (f’c)
- Exposure Class
  Note: w/cm ratio not specified
- Maximum Shrinkage
- Maximum Aggregate Size
- Modulus of Elasticity
- Is Recycled Aggregate Allowed
- Will it be Polished?

+

General Contractor Criteria
(for each application)

- Early Strength (Required to jump forms)
- Anticipated Time of Placement (during the day)
- Test Age (where appropriate consider extending beyond 28 days)
- Overall Project Schedule
- Method of Placement (Pumped? Bucket? Shotcrete?)
- Pump Distance
- Pump Rate

Procurement 2.0:
carbon as a selection criteria

Image credit: Sellen

Conventional Procurement vs "Procurement 2.0"

Conventional Procurement	Procurement 2.0
Structural Systems Decision: • Embodied carbon of alternative systems not modeled at concept design	**Structural Systems Decision:** • Design Team and/or general contractor models carbon implications of various structural systems using concept level Bill of Materials
Carbon Reduction Goals: • None	**Carbon Reduction Goals:** • Defined or Supported by the Owner • Communicated in the specifications and in the Bid Package
Specifications Approach: • Prescriptive based • w/c ratio defined in specs/general notes • Blended Cements not permitted • SCMs Capped or not permitted • No EPDs required at time of bid	**Specifications Approach:** • Performance based • w/c ratio defined by ACI and not determined by general notes • Blended Cements Permitted • SCMs Permitted • RCA Permitted • EPDs required at time of bidding

Conventional Procurement vs "Procurement 2.0"

Conventional Procurement	Procurement 2.0
Designer/Contractor Coordination • No coordination prior to Issued for Construction Drawings	**Design Team/Contractor Coordination** • Optimization opportunities discussed at design development • Identify tricky areas affecting mix selection: polished concrete, rebar congestion, white concrete
Timing of Concrete Supply Bidding • After design is complete	**Timing of Concrete Supply Bidding** • During design
Instructions to Bidders • Minimal construction schedule info • Little or no information on pumping distances and pumping rates • No requirements for EPD	**Instructions to Bidders** • Detailed construction schedule info • Pumping distances and pump rate • Detailed Info on early strength requirements for jumping forms • EPDs for all mixes required with bid • Provide Conventional Mix Solution and Carbon Optimized Mix Solution

Conventional Procurement vs "Procurement 2.0"

Conventional Procurement	Procurement 2.0

Instructions to Bidders (continued)
• All applications have 28 day f'c maturity
• No alternative bids requested with extended maturity dates
	Instructions to Bidders (continued)
	• Two sets of mix solutions requested:
	  • Conventional 28 day maturity
	  • Carbon Optimized: extended maturity dates for some applications

Decision Criteria and Information presented to Owner for Bid Award • Cost • Availability • Successful Previous Working Experience	**Decision Criteria and Information presented to Owner for Bid Award** • Cost • Availability • Successful Previous Working Experience • **Amount of GHG reduction possible by using some or all of the carbon-optimized mixes**

The Best Mix:
General contractor, supplier and design team as allies in GHG reduction

Image credit: Sellen

Use Blended Cement

Use Type 1L Cement
(aka PLC or Portland Limestone Cement)

- Immediate 10% -12% embodied GHG reduction compared to Type I
- Compatible with existing mixes
- Widely available in this region
- Widely accepted by DOTs, Sound Transit (many applications), CalTrans (pending)
- Some product specific EPDs = supply chain specific data = lower GHG data in EC3
- Long History of Successful Use:
  First in Germany in 1965
- Jurisdictions, not Science, is the limiter:
  Europe allow up to 35% limestone blended with cement

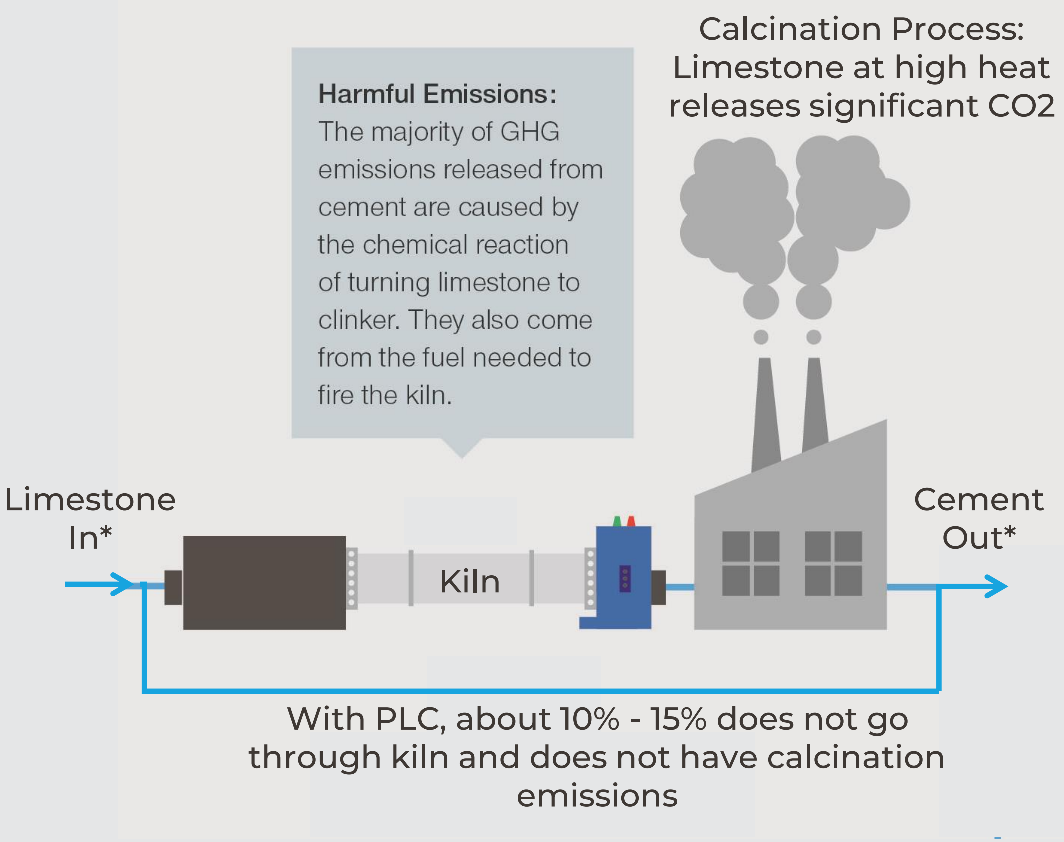


Image Credit: Sellen

* Inputs and outputs simplified for clarity

Do this, then…

1. Consider carbon implications of the type of concrete structural system
2. Be economical with the design; reduce quantities where possible
3. Use Performance Specification and remove prescriptive requirements
4. Allow Type 1L Cement in Specs and General Notes and use Supplement Cementitious Materials (Slag or Fly Ash)
5. Allow Recycled Aggregate where appropriate
6. Communicate Design and Constructability Criteria to Supplier during the bidding process

….then what: go further with Data and Technology

Image Credit: Sellen

Dial it In: Maturity Meters

Maturity Meters

- Allows for accurate strength readings by tracking temperature
- Avoids the inaccuracy of mishandled testing cylinders
- Bluetooth sensors can push data to team and alert when key values are reached
- Informs team what mix is doing the job – potentially forestalling switching to richer mix

Install Bluetooth monitors. Pour concrete

Image Credit: Giatec.com

Remote measurement of concrete temperature

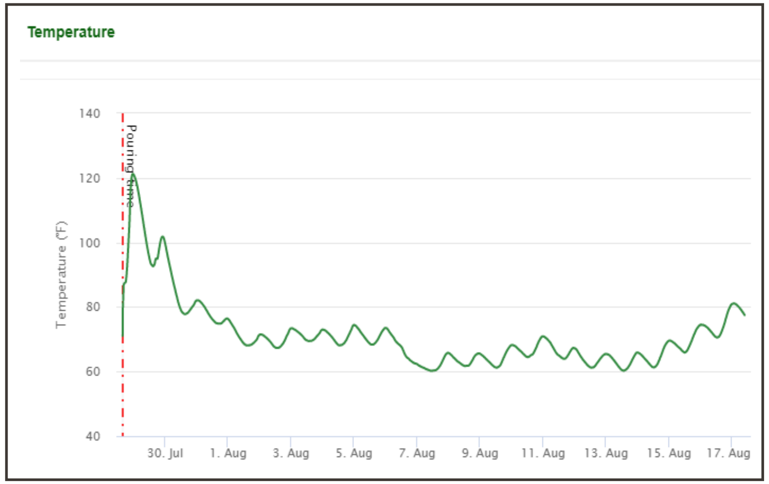


Image Credit: Giatec.com

Each mix has a unique temperature to strength curve

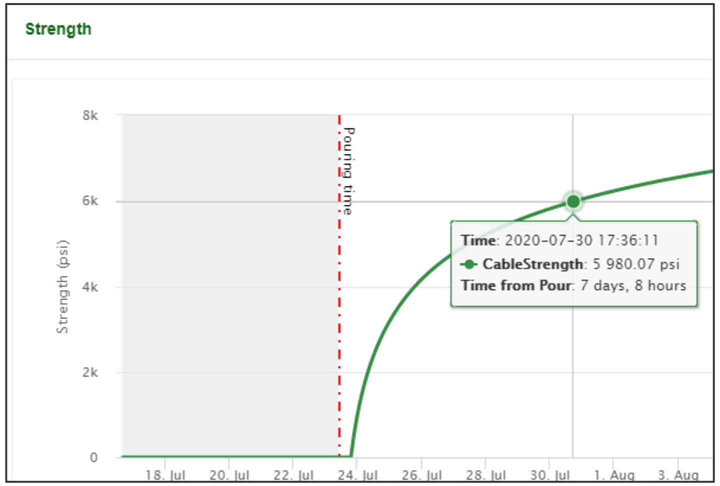
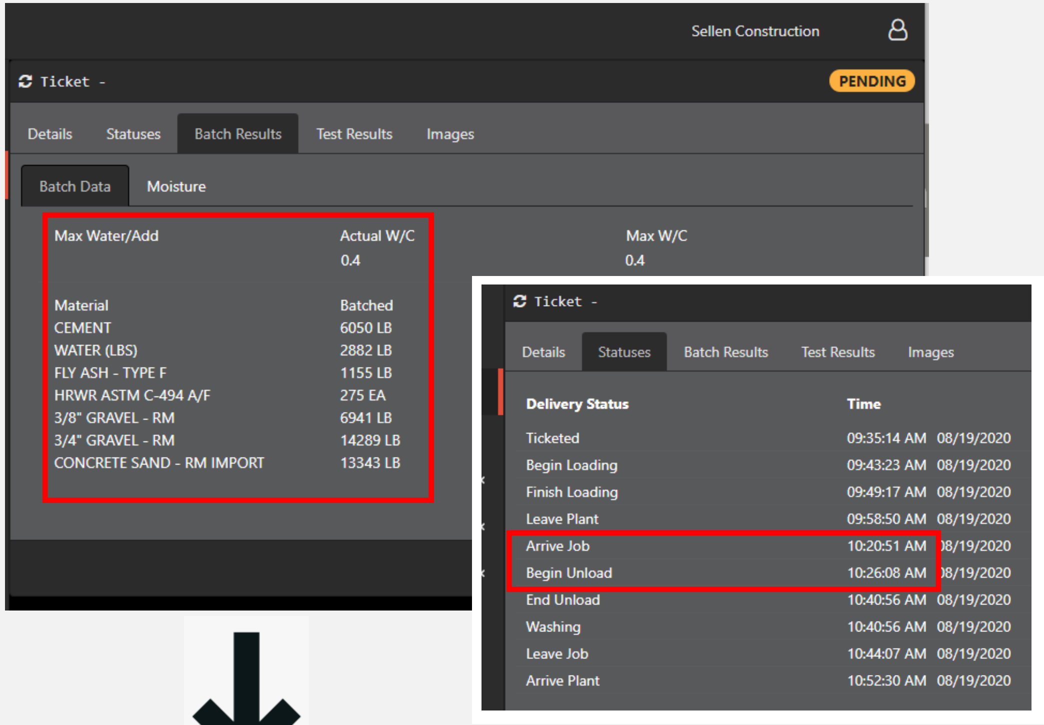


Image Credit: Giatec.com

Forecast and Track: Electronic Ticketing

Electronic Ticketing

- Moves us to the digital age – efficiency boon
- Digital format allows near-live time tracking of quantities, mixes. Paired with EPD info this builds a JTD carbon emissions picture
- Provides a stream of new data like truck wait times – another opportunity for GHG reduction
- Can export to Excel or Power BI for analytics such as tracking forecasted emissions to actual
- If not tracking the plan, we can ask “why” early enough to change course
- No longer “resultant sustainability” but predictive sustainability



Analysis to:

- Reduce Idling Time
- Track Optimized Mix Use

Key Takeaways:

- There are client, business and legislative drivers for lower carbon concrete in this market.
- The demand for material disclosure (EPDs) is growing and in some projects mix-specific EPDs are required
- Today there are implementable and meaningful strategies to reduce emissions from concrete
- By designers providing performance specifications and contractors providing more constructability information at bid time, suppliers can provide carbon optimized solutions
- Beyond the mix, there are jobsite strategies to fine tune construction operations and further reduce emissions

Image credit: Sellen

Thanks

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