Mix Design to Ensure Sustainability and Resilience of Concrete

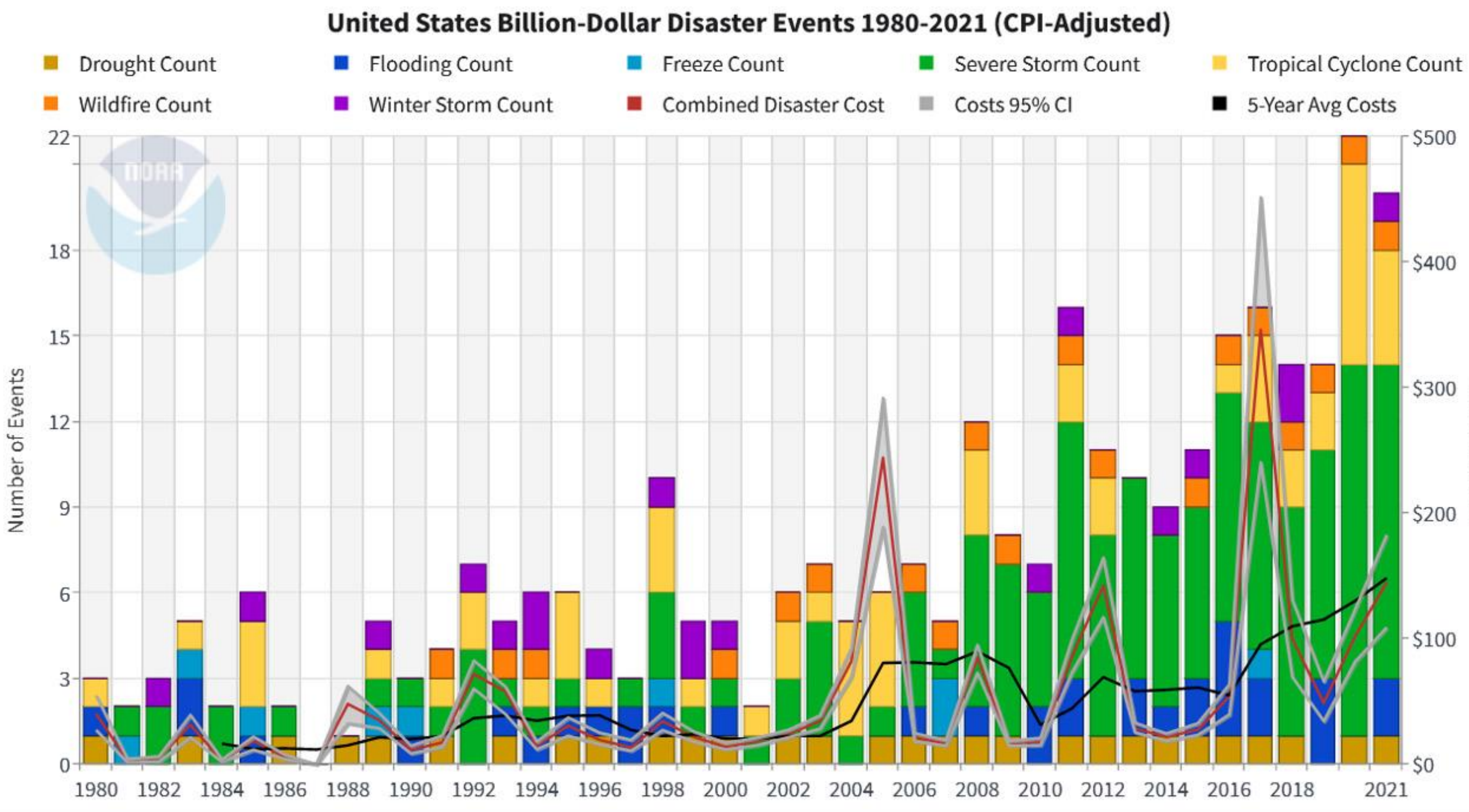
B Perrie
Cement and Concrete SA

Definitions

- Sustainability
  - sustainability deals with known events that can be quantified and entails balancing economic, societal and environmental pillars

Definitions

- Resilience
  - Is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly after a disruptive event such as a flood or earthquake
  - Forms the foundation of all three pillars of sustainability


United States Billion-Dollar Disaster Events 1980-2021 (CPI-Adjusted)
Drought Count
Flooding Count
Freeze Count
Severe Storm Count
Tropical Cyclone Count
Wildfire Count
Winter Storm Count
Combined Disaster Cost
Costs 95% CI
5-Year Avg Costs
Number of Events
Cost in Billions
0
3
6
9
12
15
18
22
$0
$100
$200
$300
$400
$500
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2021

The Challenge

To find a way to build more sustainable and resilient structures using concrete while minimizing the carbon emissions

Full Value Chain

- Structure / Pavement design
- Material production
- Construction
- Use stage
- End of life including recycling

Essential to use Life Cycle Cost Analysis (LCCA)and Life Cycle Analysis (LCA)

Full Value Chain

- Designs should optimize material usage
- Reducing CO_2 emissions
- Optimizing concrete mix designs to ensure optimized aggregate grading and cement content
- Use appropriate tests

Optimizing designs to minimize material usage

- Onus on designers to look carefully at their designs especially assessing them in terms of LCCA and LCA
- Use the most up to date design tools.

Reducing CO2 emissions

- CCSA Partners have committed to Net Zero Carbon by 2050
- Local cement standards allow wide range of cements that should be considered
- Increase use of extended cements

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass [a]) – Main constituents: Clinker K	Blast-furnace slag S	Silica fume D[b]	Pozzolana: Natural P	Pozzolana: Natural calcined Q	Fly ash: Siliceous V	Fly ash: Calcareous W	Burnt shale T	Limestone L	Limestone LL	Minor additional Cons-tituents
CEM I	Portland cement	CEM I	95 - 100	-	-	-	-	-	-	-	-	-	0 - 5
CEM II	Portland-slag cement	CEM II/A-S	80 - 94	6 - 20	-	-	-	-	-	-	-	-	0 - 5
		CEM II/B-S	65 - 79	21 - 35	-	-	-	-	-	-	-	-	0 - 5
	Portland-silica fume cement	CEM II/A-D	90 - 94	-	6 – 10	-	-	-	-	-	-	-	0 - 5
	Portland-pozzolana Cement	CEM II/A-P	80 - 94	-	-	6 - 20	-	-	-	-	-	-	0 - 5
		CEM II/B-P	65 - 79	-	-	21 - 35	-	-	-	-	-	-	0 - 5
		CEM II/A-Q	80 - 94	-	-	-	6 - 20	-	-	-	-	-	0 - 5
		CEM II/B-Q	65 - 79	-	-	-	21 - 35	-	-	-	-	-	0 - 5
	Portland-fly ash cement	CEM II/A-V	80 - 94	-	-	-	-	6 - 20	-	-	-	-	0 - 5
		CEM II/B-V	65 - 79	-	-	-	-	21 - 35	-	-	-	-	0 - 5
		CEM II/A-W	80 - 94	-	-	-	-	-	6 - 20	-	-	-	0 - 5
		CEM II/B-W	65 - 79	-	-	-	-	-	21 - 35	-	-	-	0 - 5
	Portland-burnt shale cement	CEM II/A-T	80 - 94	-	-	-	-	-	-	6 - 20	-	-	0 - 5
		CEM II/B-T	65 - 79	-	-	-	-	-	-	21 - 35	-	-	0 - 5
	Portland-limestone cement	CEM II/A-L	80 - 94	-	-	-	-	-	-	-	6 - 20	-	0 - 5
		CEM II/B-L	65 - 79	-	-	-	-	-	-	-	21 - 35	-	0 - 5
		CEM II/A-LL	80 - 94	-	-	-	-	-	-	-	-	6 - 20	0 - 5
		CEM II/B-LL	65 - 79	-	-	-	-	-	-	-	-	21 - 35	0 - 5
	Portland-composite cement (c)	CEM II/A-M	80 - 88	12 - 20									0 - 5
		CEM II/B-M	65 - 79	21 - 35									0 - 5
CEM III	Blast furnace cement	CEM III/A	35 - 64	36 - 65	-	-	-	-	-	-	-	-	0 - 5
		CEM III/B	20 - 34	66 - 80	-	-	-	-	-	-	-	-	0 - 5
		CEM III/C	5 - 19	81 - 95	-	-	-	-	-	-	-	-	0 - 5
CEM IV	Pozzolanic cement (c)	CEM IV/A	65 - 89	-	11 - 35					-	-	-	0 - 5
		CEM IV/B	45 - 64	-	36 - 55					-	-	-	0 - 5
CEM V	Composite cement (c)	CEM V/A	40 - 64	18 - 30	-	18 - 30			-	-	-	-	0 - 5
		CEM V/B	20 - 38	31 - 49	-	31 - 49			-	-	-	-	0 - 5

Notes

(a) The values in the table refer to the sum of the main and minor additional constituents.

(b) The proportion of silica fume is limited to 10%.

(c) In portland-composite cements CEM II A-M and CEM II B-M, in pozzolanic cements CEM IV A and CEM IV B, and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement.

Main types	Notation of the seven products (types of sulfate resisting common cement)		Composition (percentage by mass[a]) Main constituents: Clinker K	Blast furnace slag S	Pozzolana natural P	Siliceous fly ash V	Minor additional constituents
CEM I	Sulfate resisting portland cement	CEM I-SR 0	95 - 100	-	-	-	0 - 5
		CEM I-SR 3					
		CEM I-SR 5					
CEM III	Sulfate resisting blast furnace cement	CEM III/B-SR	20 - 34	66 – 80	-	-	0 - 5
		CEM III/C-SR	5 - 19	81 - 95	-	-	0 - 5
CEM IV	Sulfate resisting pozzolanic cement	CEM IV/A-SR	65 - 79	-	21 - 35		0 - 5
		CEM IV/B-SR	45 - 64	-	36 - 55		0 - 5

[a] The values refer to the sum of main and minor constituents

Where:

CEM I-SR 0	C_3A content of the clinker	= 0%
CEM I-SR 3	C_3A content of the clinker	≤ 3%
CEM I-SR 5	C_3A content of the clinker	≤ 5%
CEM III/B-SR	C_3A content of the clinker	= no requirement
CEM III/C-SR	C_3A content of the clinker	= no requirement
CEM IV/A-SR	C_3A content of the clinker	≤ 9%
CEM IV/B-SR	C_3A content of the clinker	≤ 9%

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Main types	Notation of the products (types of cements)		Composition (percentage by mass a)										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						Natural	Natural calcined	Siliceous	Calcareous				
	Type name	Type notation	K	S	D [b]	P	Q	V	W	T	L [c]	LL [c]	
CEM II	Portland composite cement[d]	CEM II/C-M	50 - 49	36 - 50									0 - 5
CEMVI	Composite cement	CEM VI (S-P)	35-49	31-59	-	6-20	-	-	-	-	-	-	0 - 5
		CEM VI (S-V)	35-49	31-59	-	-	-	- 6-20	-	-	-	-	0 - 5
		CEM VI (S-L)	35-49	31-59	-	-	-	-	-	-	6-20	-	0 - 5
		CEMVI (S-LL)	35-49	31-59	-	-	-	-	-	-	-	6-20	0 - 5

a) The values in the table refer to the sum of the main and minor additional constituents.
b) In case of the use of silica fume, the proportion of silica fume is limited to 6-10 % by mass.
c) In case of the use of limestone, the proportion of limestone (sum of L, LL) is limited to 6-20 % by mass.
d) The number of main constituents other than clinker is limited to two and these main constituents shall be declared by designation of the cement. (for example, see clause 6)

Strength class	Compressive strength, MPa				Initial setting time
	Early strength		Standard strength		
	2 days	7 days	28 days		min
32,5L[a]	-	≥12,0	≥32,5	≤52,5	≥75
32,5N	-	≥16,0			
32,5R	≥10,0	-			
42,5L[a]	-	≥16,0	≥42,5	≤62,5	≥60
42,5N	≥10,0	-			
42,5R	≥20,0	-			
52,5L[a]	≥10,0	-	≥52,5	-	≥45
52,5N	≥20,0	-			
52,5R	≥30,0	-			

[a] Strength class only defined for CEM III cements

New cements/extenders

- SANS 50197-5 Portland-composite cement and Composite cement CEM VI published by SABS
- Known as limestone calcined clay cements (LC3) Note: *No LOA from NRCS yet*
- New extender LC2 allowed in 50197-1 but no spec for separate extender.
- Need to consider going forward

New aggregate specification

- SANS 1083 *Aggregates from Natural Sources – Aggregates for Concrete* being replaced
- New SANS 1083 *Aggregates for Construction*
- Covers:
  - – Aggregates from natural sources
  - – Manufactured aggregates, e.g. slag and ash
  - – Recycled aggregates

New aggregate specification

- New SANS 1083 *Aggregates for Construction*
- Four Parts:
  - Part 1 Aggregates for Concrete
  - Part 2 Aggregates for Mortar and Plaster
  - Part 3 Aggregates for Asphalt
  - Part 4 Aggregates for Surfacing

Optimizing concrete mix designs

- Identify the best and most suitable materials – cheapest is often more expensive
- Optimize gradings to ensure maximum packing and minimum paste content
- Consider benefits of extended cements
- Assess placeability
- Assess early age shrinkage and cracking

While our standards address some aspects of ensuring sustainability and resilience, do they do enough or is there more that can be done?

Concrete Pavements

COTO Ch 6 Material Requirements

- Cement to SANS 50197-1 ≥ 32,5 N
- Extenders to SANS 50450-1 or SANS 55167-1
- Blends of cement and extender ≤ 20% **??????**
- Aggregates to SANS 1083 **????????**
- Recycled aggregate**????**

COTO Chap 6 Mix Requirements

- Water-cement ratio ≤ 0,53
- Cementitious content ≥ 320 kg/m^3
- Specified Compressive Strength – highest of
  - 35 MPa at 28 days
  - 0,85 fc_1 (28 day) corres to 4,5 MPa flexure
  - 0,85 fc_2 (28 day) corres to w/c of 0,53
  - 0,85 fc_3 (28 day) corres to cement content of 320kg/m3

COTO Chap 6 Requirements (cont.)

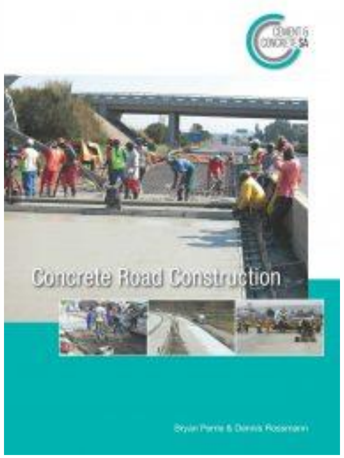
- Results of all the specified properties
- Relationship of f_c and f_f at three w/c 0,48, 0,53 and 0,58
- Effect of variations in admixture on workability, setting and strength gain
- Effect of three w/c on concrete consistence
- Assessment of sawing ability, tining and placeability

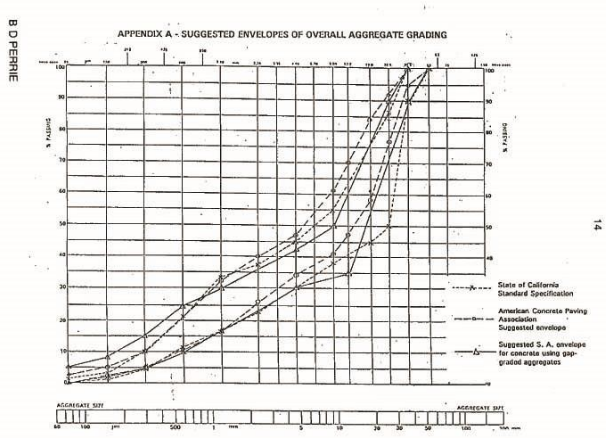
COTO Chap 6 Requirements (cont.)

- Do not address:
  - New cements and extenders or increased extenders
  - Requirements to optimize aggregate grading and/or packing capacity (Graph in manual)
  - Paste volume
  - Early age shrinkage and cracking potential
  - Assessment of sawing ability and placeability
  - Insertion of dowels/tiebars

Guidance

- Appendix A of the Concrete Road Construction Manual provides guidance on proportioning and assessment of pavement mixes
- See also P Taylor presentation





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Concrete Structures

COTO Ch 13

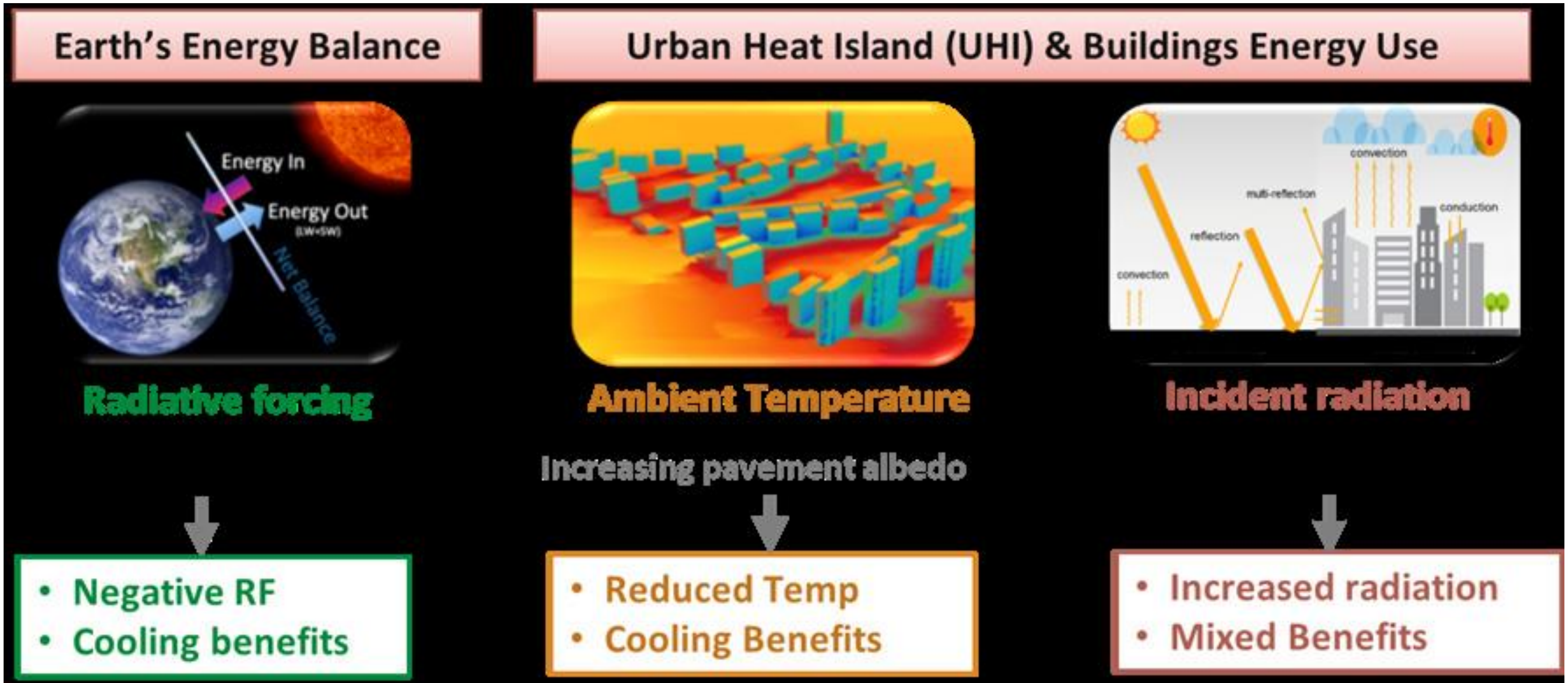
- Far more detailed than Ch 6 for pavements
- Very detailed in terms of durability requirements
- Some confusing criteria

COTO Chap 13 Requirements

- Do not address:
  - New cements
  - Recycled aggregates
  - Requirements to optimize aggregate grading and/or packing capacity
  - Paste volume
  - Early age shrinkage and cracking potential

Use Phase Impacts

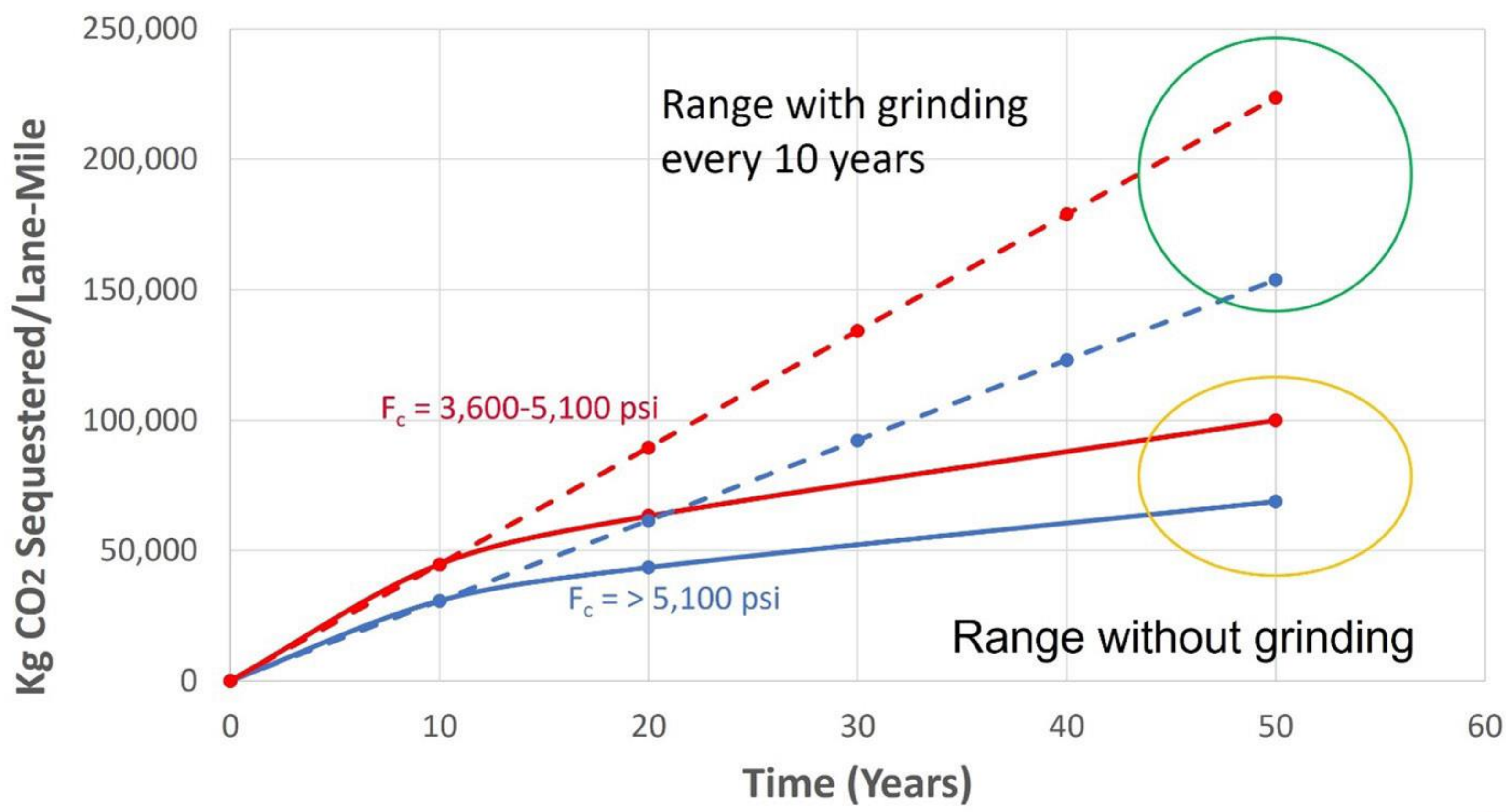
- Effect of Albedo



Use Phase Impacts

- CO_2 absorption
- Concrete acts as a CO_2 sink
- Reduces over time
- Diamond grinding therefore better than overlaying

Use Phase Impacts



End of life

- Concrete fully recyclable
- When recycled, accelerates the carbonation process

Conclusions

- Concrete most sustainable, resilient choice for both pavements and structures
- Numerous ways to decrease embodied and long-term environmental impacts
- Need to look more closely at mix designs to further improve both sustainability and resilience

Thank you

Questions?