Portland-Limestone Cement: An Option to Make Concrete Even Greener

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PLC – The Concrete Difference

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Today's Objectives

- What is a portland-limestone blended cement
- Why use it
- How is it made
- How does it perform in concrete
- Some examples
- Questions

Portland-Limestone Cement

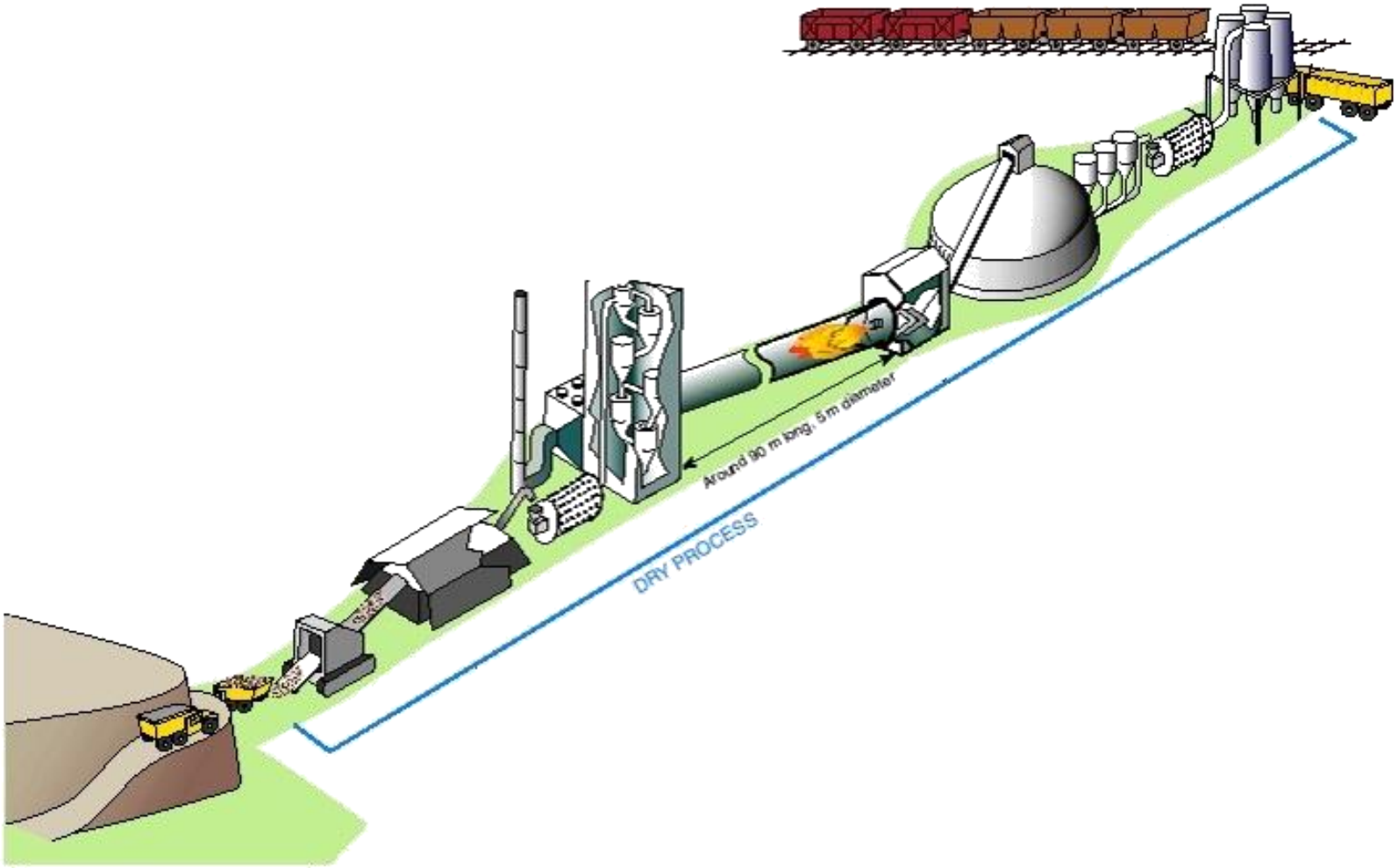
- What is a PLC?
  - Type IL blended cement in ASTM C595/AASHTO M 240
    - 5% to 15% limestone by mass
  - Option to implement proven technology to obtain desired performance and improve sustainability of concrete

Typical US Cement Composition:

Material	Portland Cement	PLC
Clinker	91 %	83%
Gypsum	6 %	6 %
Limestone	3 %	11 %

Up to 5% Limestone in Portland Cement – Up to 15% Limestone in PLC

Cement Manufacture



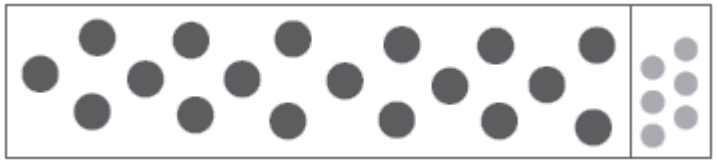
How is PLC Different?

- PLC is made by intergrinding regular clinker with up to 15% limestone while regular portland cement contains up to 5% limestone
- PLC is a finer ground product than regular portland cement

PORTLAND CEMENT

95% Ground Clinker

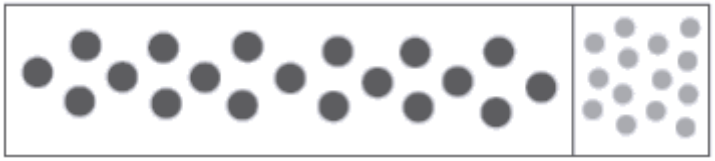
5% limestone



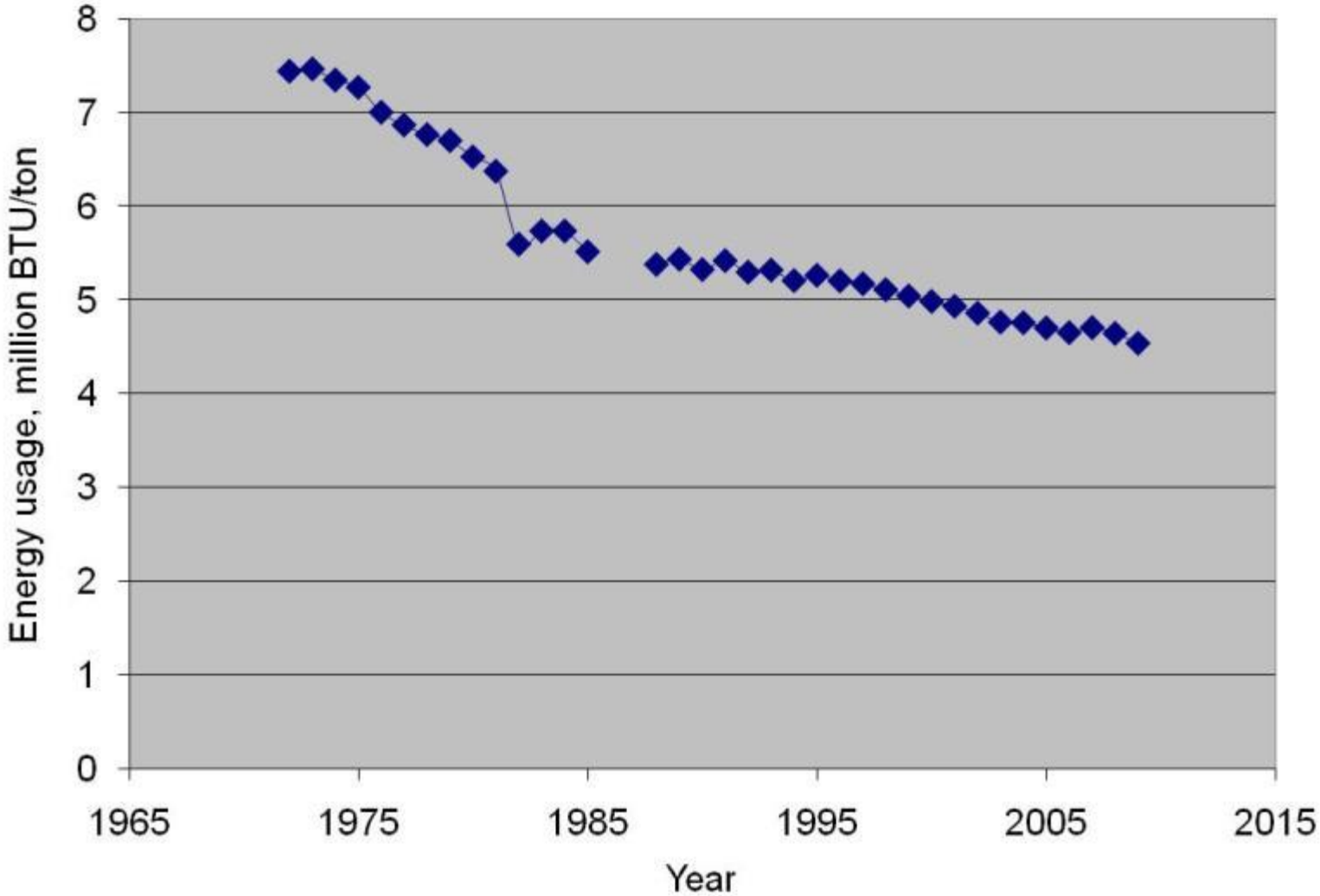
PLC

85% Ground Clinker

15% limestone



Energy to Produce Cement

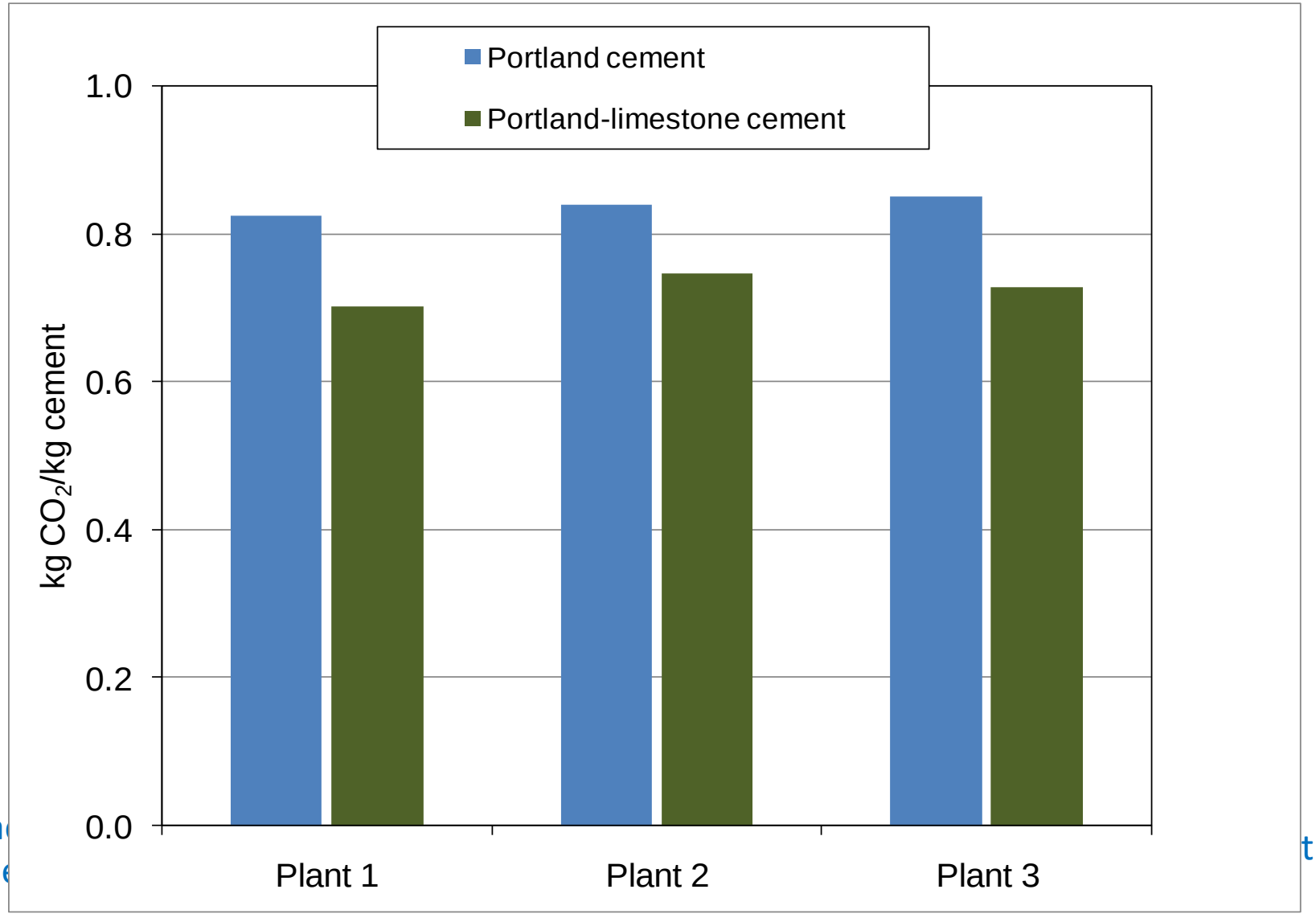


Some CO_2 Facts

- Each Tonne of clinker results in an unavoidable release of ~525 kg of CO_2 due to calcination

- This is about 60% of the total CO_2 emissions associated with cement manufacturing and occur regardless of the fuels used to support the kiln process

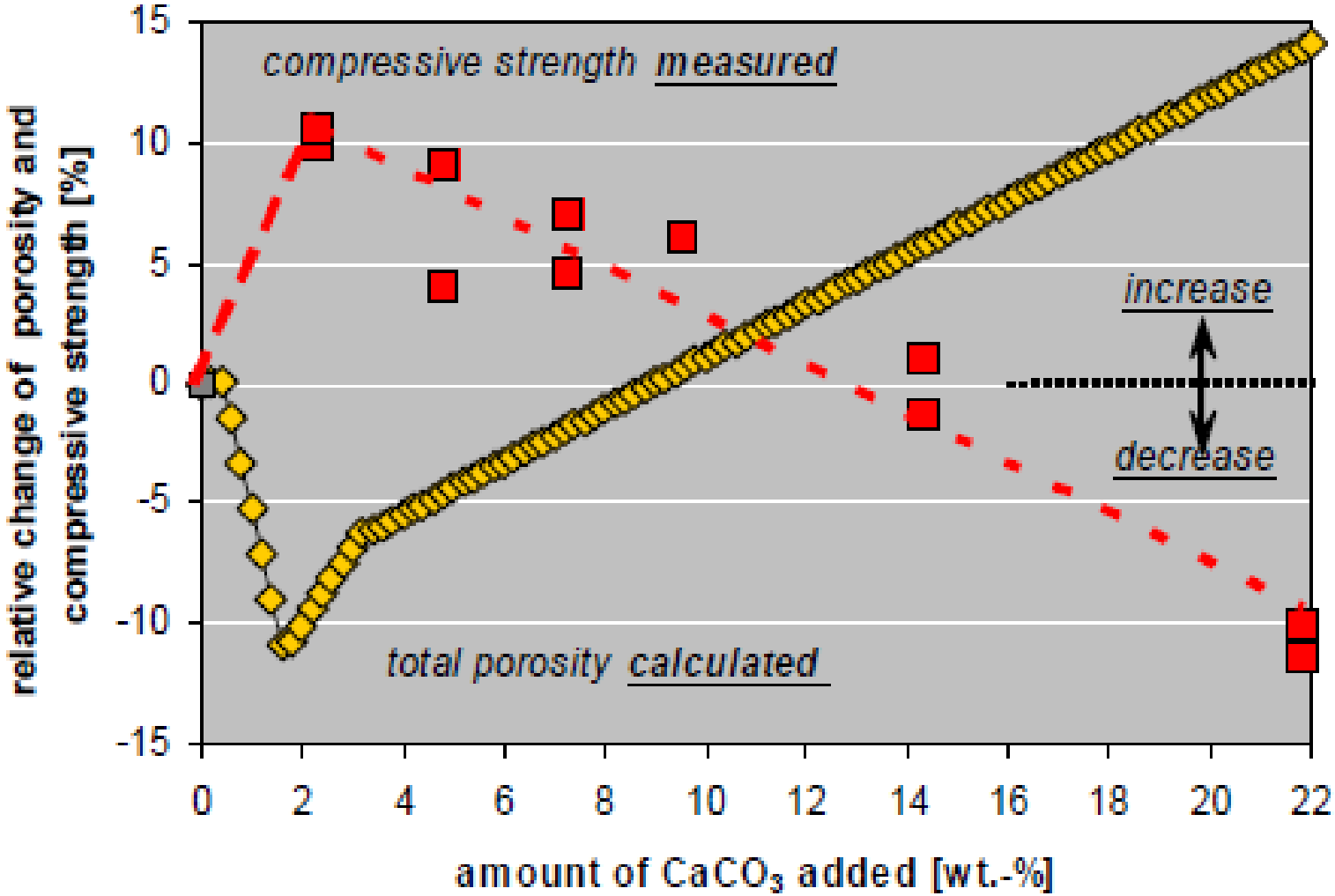
Environmental Benefits



History of Limestone in Cements

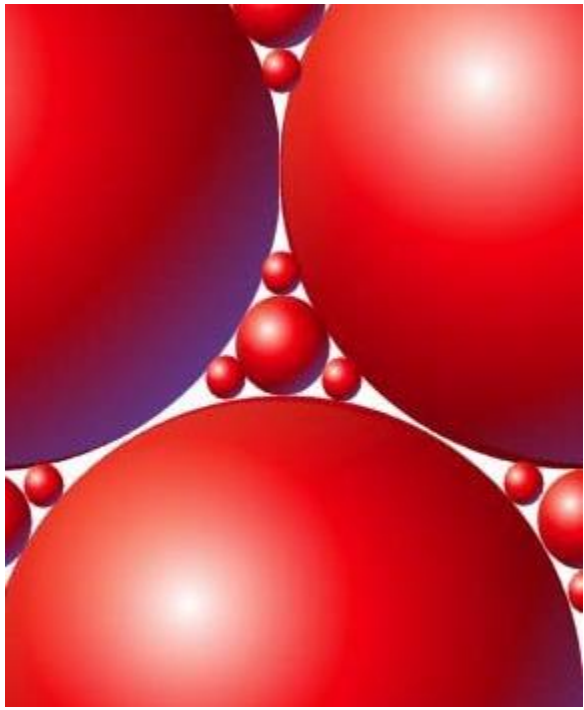
- 1965 Cement with 20% limestone in Germany for specialty applications
- 1979 French cement standards allows limestone
- 1983 CSA A5 allows up to 5% limestone in portland cement
- 1990 15±5% limestone blended cements routinely used in Germany
- 1992 UK specs allows up to 20% in limestone cement
- 2000 EN 197-1 allows 5% MAC (typ. limestone) in all 27 common cements
- 2000 EN 197-1 creates CEM II/A-L (6-20%) and CEM II/B-L (21-35%)
- 2004 ASTM C 150 allows 5% in Types I-V
- 2006 CSA A3001 allows 5% in other Types than GU
- 2007 AASHTO M85 allows 5% in Types I-V
- 2008 CSA A3001 includes PLC with 5%-15% limestone
- 2012 ASTM C595/AASHTO M 240 include PLC with 5% to 15% limestone

Why 15%?


compressive strength measured
total porosity calculated
increase
decrease
relative change of porosity and compressive strength [%]
amount of $CaCO_3$ added [wt.-%]
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
22

How Limestone Works

- Particle packing
  - Improved particle size distribution
- Nucleation
  - Surfaces for precipitation
- Chemical reactions
  - Only a small amount, but…



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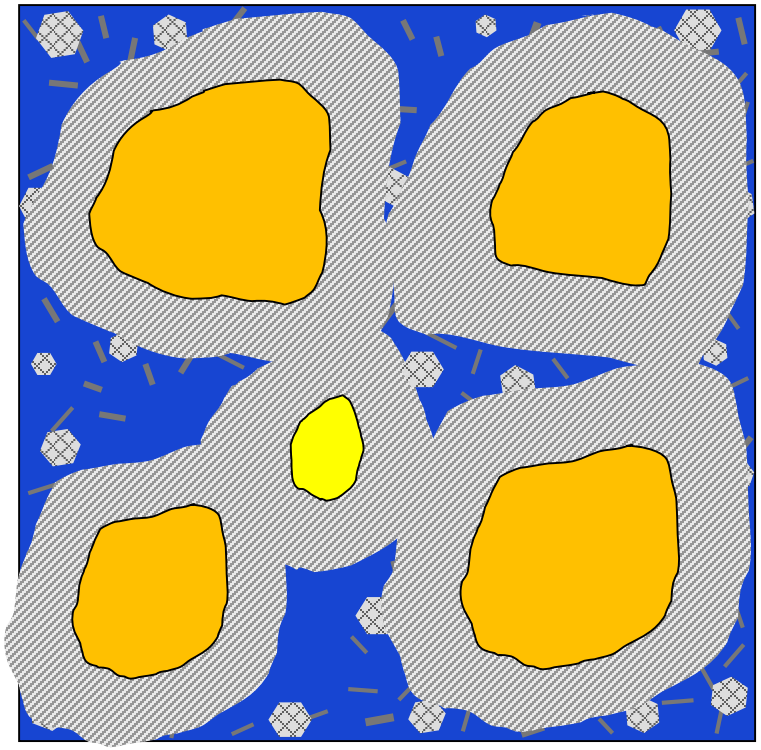


How Limestone Works

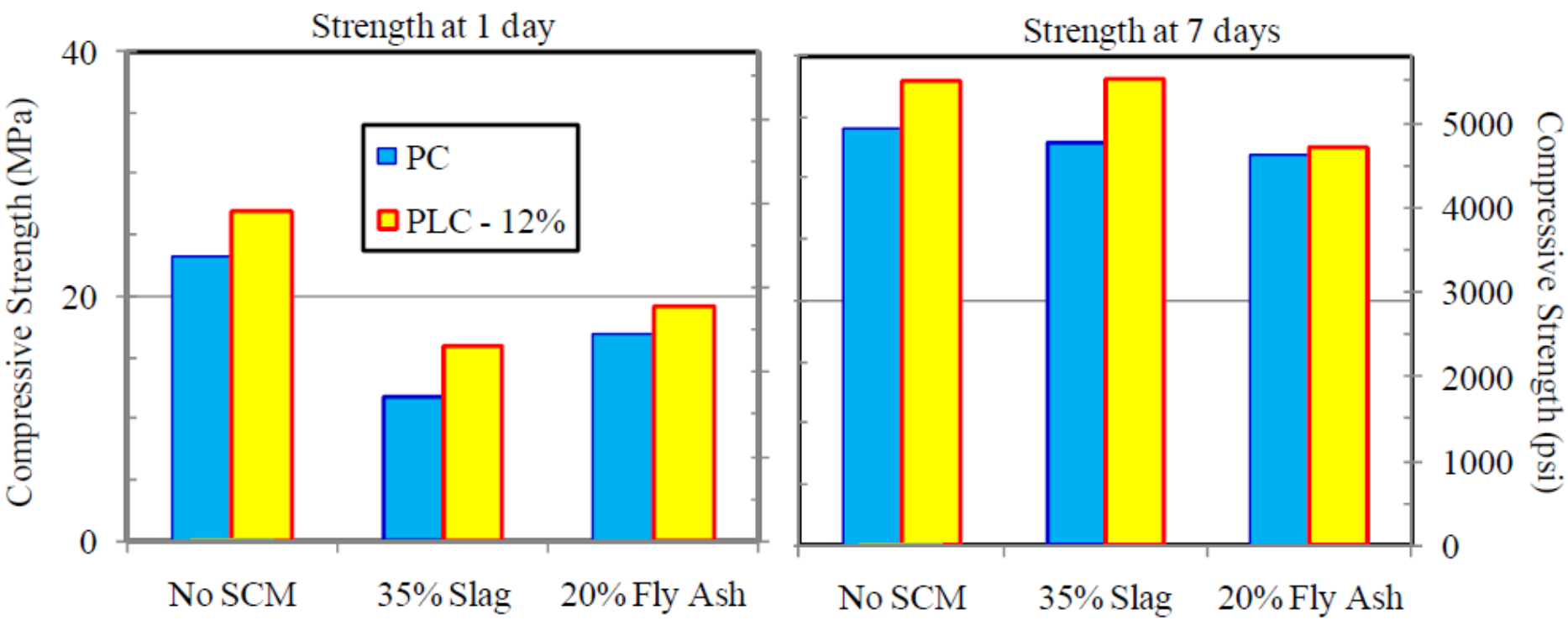
- Particle packing
  - Improved particle size distribution
- Nucleation
  - Surfaces for precipitation
- Chemical reactions
  - Only a small amount, but…

Ca^{2+} $CaOH^{+}$

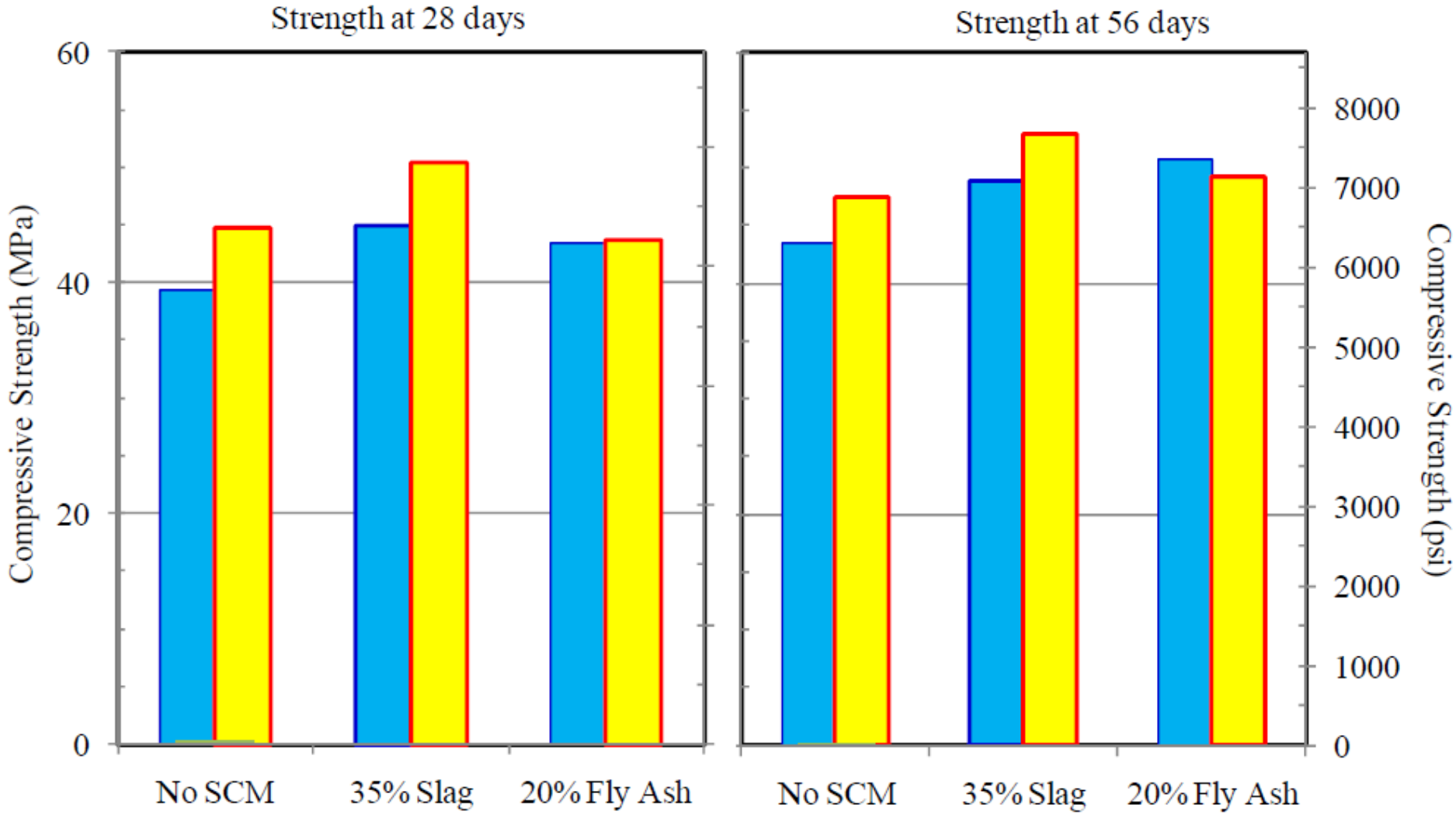
$HSiO_3^{-}$ SO_4^{2-}

CO_3^{2-}

Strength


Strength at 1 day
Strength at 7 days
Compressive Strength (MPa)
Compressive Strength (psi)
40
20
0
5000
4000
3000
2000
1000
0
PC
PLC - 12%
No SCM
35% Slag
20% Fly Ash
No SCM
35% Slag
20% Fly Ash

Strength



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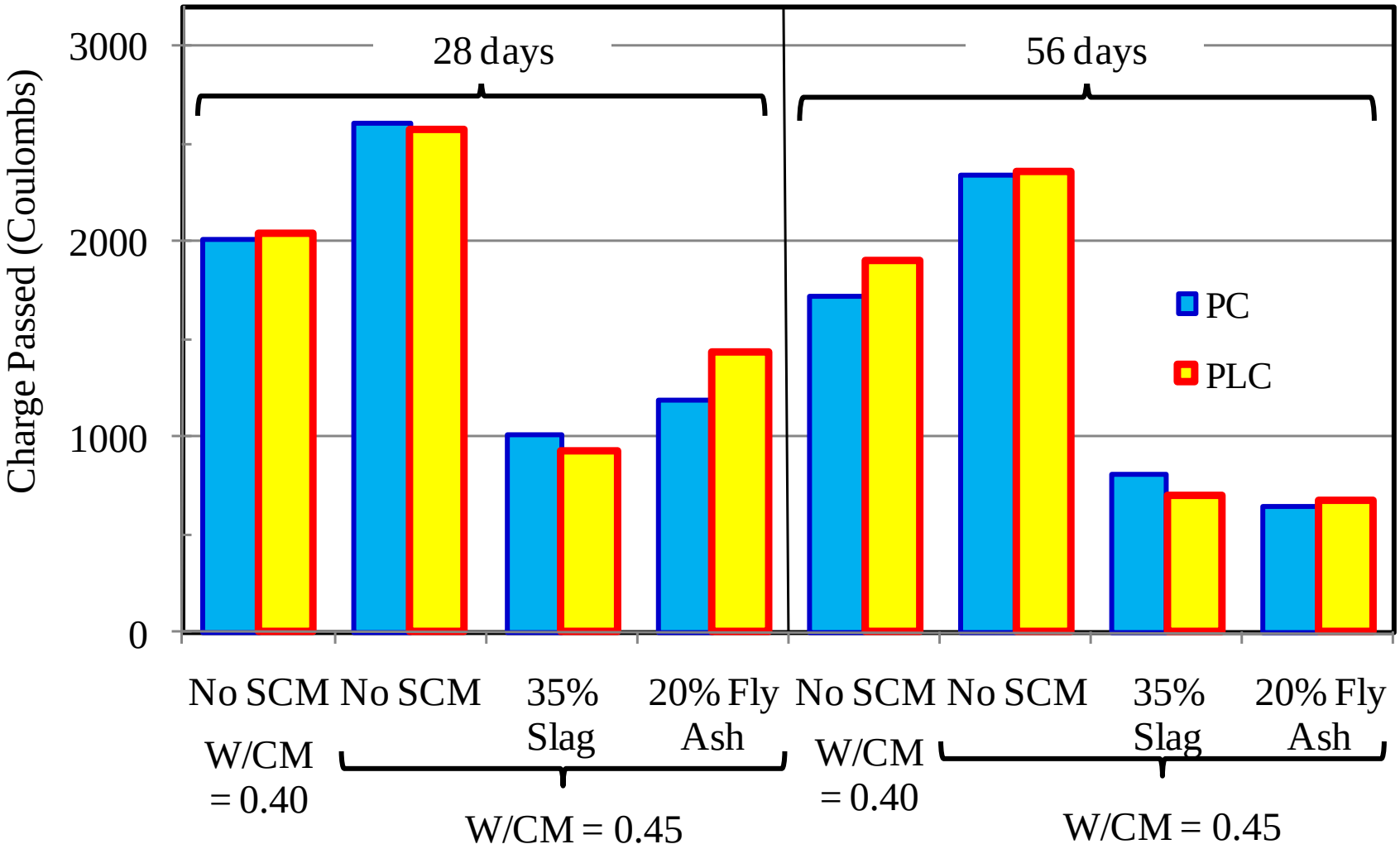
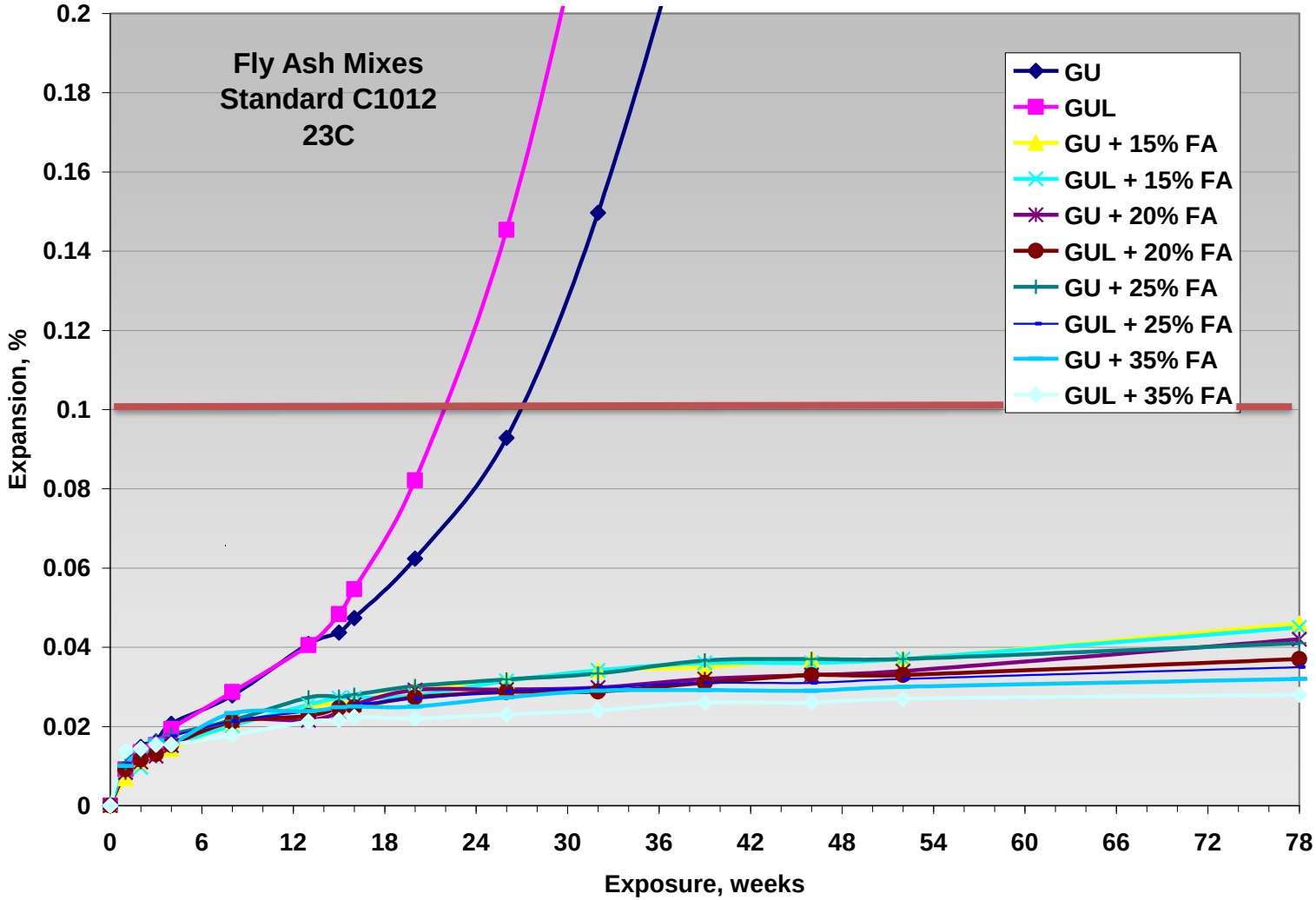
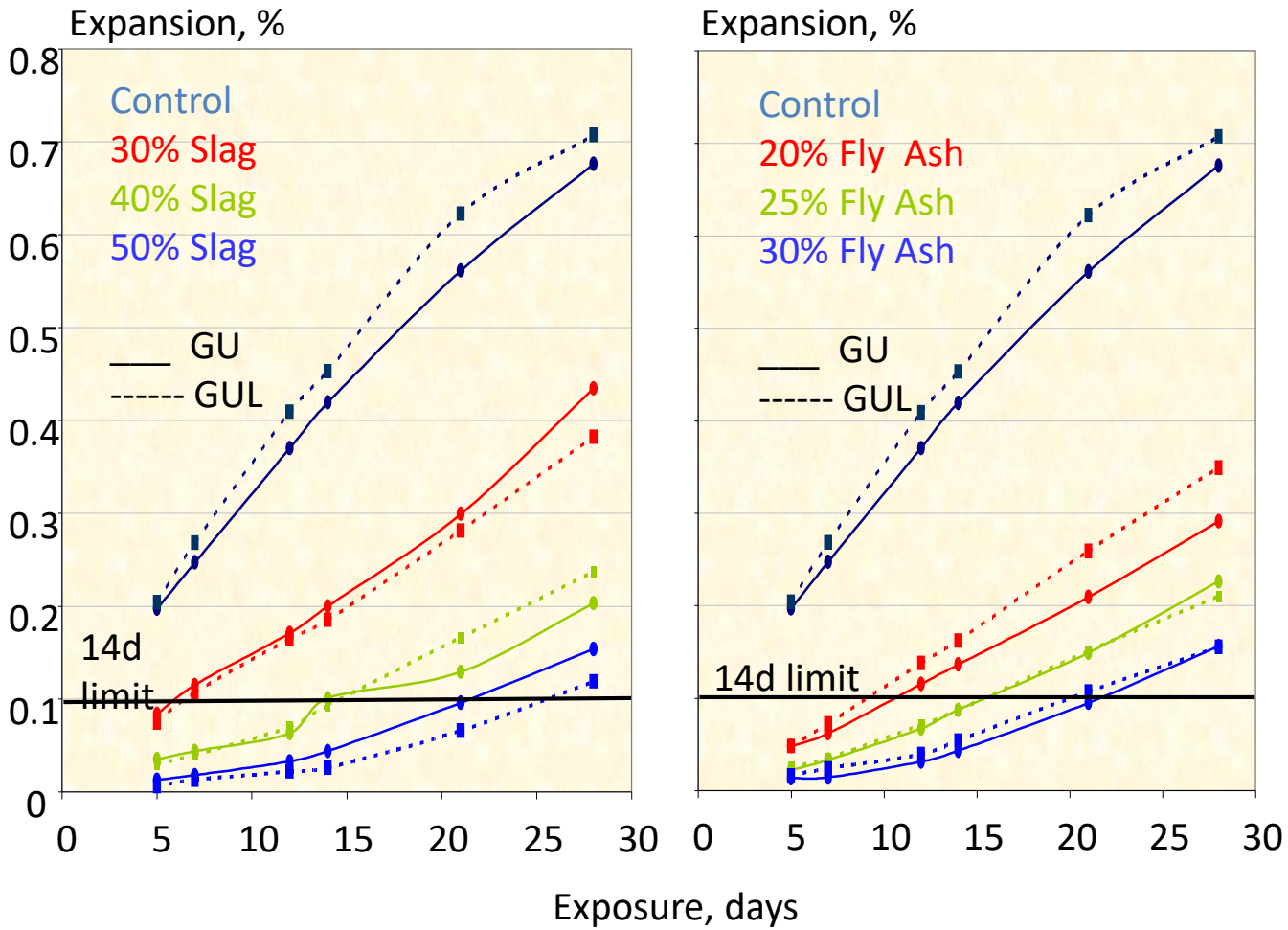
Permeability T 277/C1202



Sulfate Resistance C1012



ASR - Accelerated Mortar Bar Test

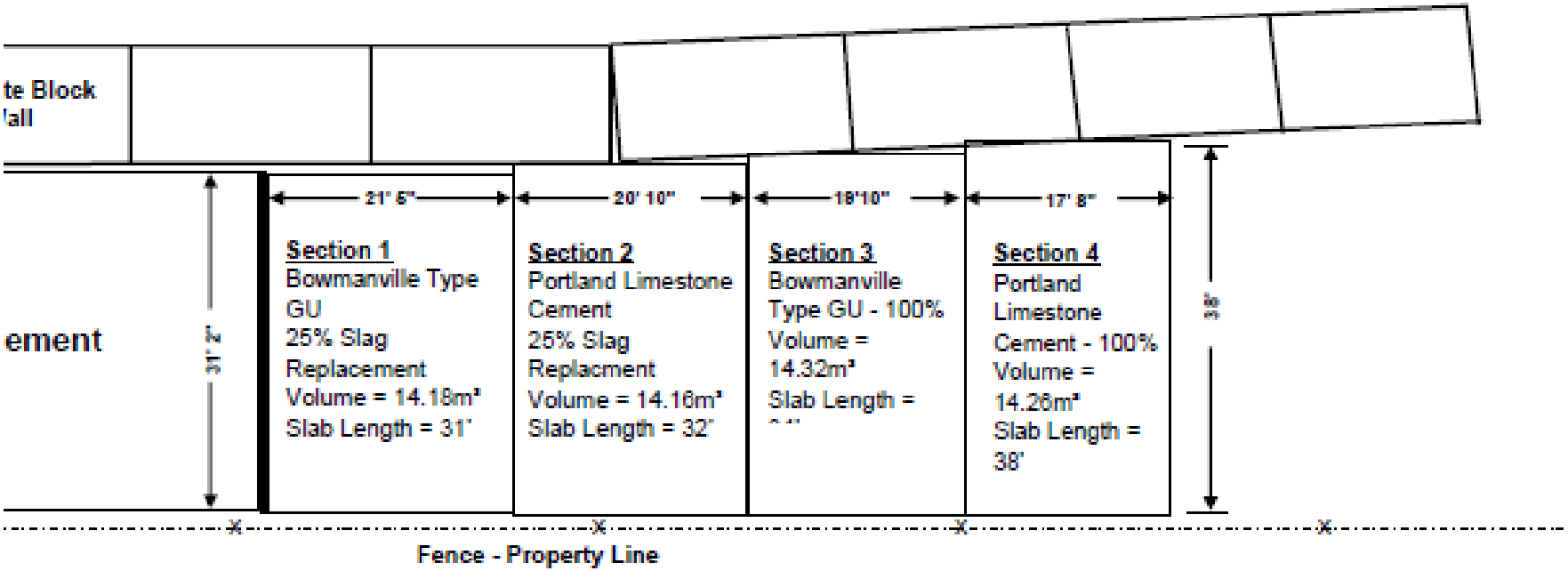


PLC Application in Pavement

- A ready-mixed concrete plant yard was paved in 4 sections with 4 different cementitious mixes in 2009
- 100% Type I
- 100% Type IL
- Type I with 25% slag
- Type IL with 25% slag

PLC Application in Pavement

Placed November 3rd 2009, pavement is 9” thick



PLC APPLICATION IN PAVEMENT

Then and now

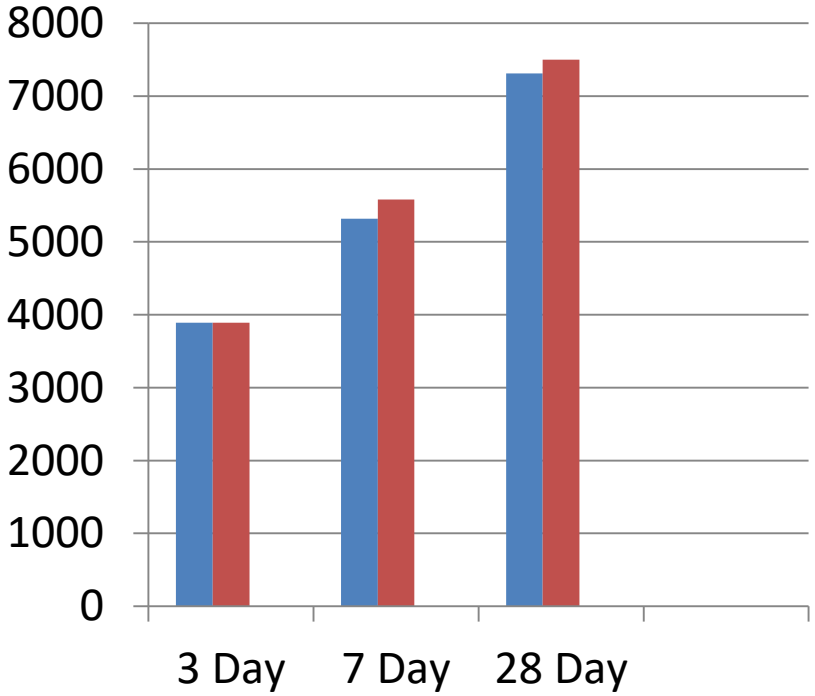
November 3rd, 2009

October 30th, 2018

ODOT Approved concrete mix

QC 1 4000psi <2000 rcp

- Type IL /I 450 lb
- Slag cem 150 lb
- W/C 0.45
- Slump 5.75/8
- Air 7.2%/6.8%
- RCP 1147/1171



IL MTO Field Trial – Sarnia (October 2011)

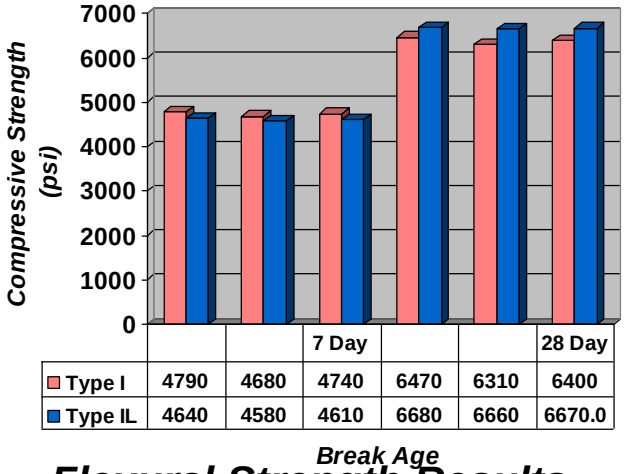
Highway 402 Westbound – East of Front Street (Sarnia, Ontario)

- The application was slip formed barrier walls (MTO Contract) located on the north side of HW 402 Westbound in Sarnia, Ontario
- Type I with 25% Slag
- Type IL with 25% slag
- Low slump concrete 13/64th to 1 inch
- Air Content (5-8%)
- The barrier walls are exposed to harsh weather conditions
- Strength and durability testing was completed by University of Toronto, along with other third party laboratories showing similar results when comparing Type I and IL

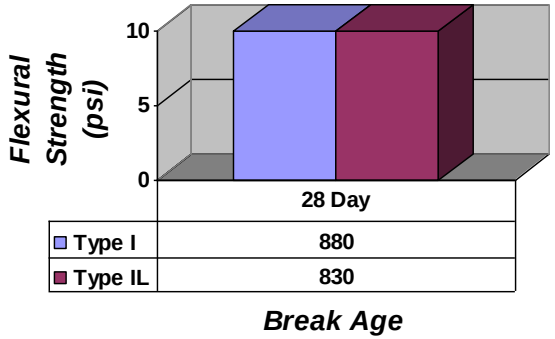
IL MTO Field Trial – Sarnia (October 2011)

Compressive Strength Results

Cylinders Cast at Plant



Flexural Strength Results



IL MTO Field Trial – Sarnia (October 2011)

Concrete's Ability to Resist Chloride Ion Penetrability
ASTM C1202

Mix Identification	28 Day Rapid Chloride Permeability (Coulombs)	
	Cast Cylinders	In Situ Cores
Type I	1391	1530
Type IL	1470	1301

Hardened Air Void Analysis
ASTM C457

Mix Identification	Hardened Air Void Analysis (ASTM C457)					
	Cast Cylinders			In Situ Cores		
	Air Content (%)	Specific Surface (mm^{-1})	Spacing Factor (µm)	Air Content (%)	Specific Surface (mm^{-1})	Spacing Factor (µm)
Type I	4.5	30.72	167	3.1	31.83	197
Type IL	4.1	41.12	130	2.2	42.99	184
Specifications	***3.0 minimum***	***-***	***< 230***	***3.0 minimum***	***-***	***< 230***

IL MTO Field Trial – Sarnia (October 2011)

Freeze Thaw Durability

Cast (75 x 75 x 285mm) Prisms

ASTM C666

Mix Identification	Freeze Thaw Durability		
	Average Mass Loss (%)	Average Length Change (%)	Average Durability Factor (%)
Load 3 - GU	-1.678	0.022	93.92
Load 6 - GUL	-1.624	0.020	90.19

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

300 x 250 x 75mm LS-412 Slabs

Mix Identification	Average Salt Scaling Loss (kg/m²)	
	Cast Slabs @ 50 Cycles	In Situ Cut Slabs @ 50 Cycles
Load 3 - GU	0.27	3.33
Load 6 - GUL	0.32	1.30
MTO Specification	***0.80 kg/m² max @ 50 cycles***	

IL MTO Field Trial – Sarnia (October 2011)

Linear Shrinkage
MTO LS-435

Mix Identification	Shrinkage (%)				
	1	3	7	14	28
Load 3 – GU – Prism 1	-0.006	0.012	-0.019	-0.026	-0.034
Load 3 – GU – Prism 2	-0.007	-0.013	-0.022	-0.029	-0.036
Load 3 – GU – Prism 3	-0.007	-0.012	-0.021	-0.028	-0.036
Average	***-0.007***	***-0.004***	***-0.021***	***-0.028***	***-0.035***
Load 6 – GUL – Prism 1	-0.007	-0.012	-0.019	-0.027	-0.034
Load 6 – GUL – Prism 2	-0.007	-0.011	-0.017	-0.025	-0.032
Load 6 – GUL – Prism 3	-0.007	-0.012	-0.019	-0.025	-0.032
Average	***-0.007***	***-0.012***	***-0.018***	***-0.026***	***-0.033***

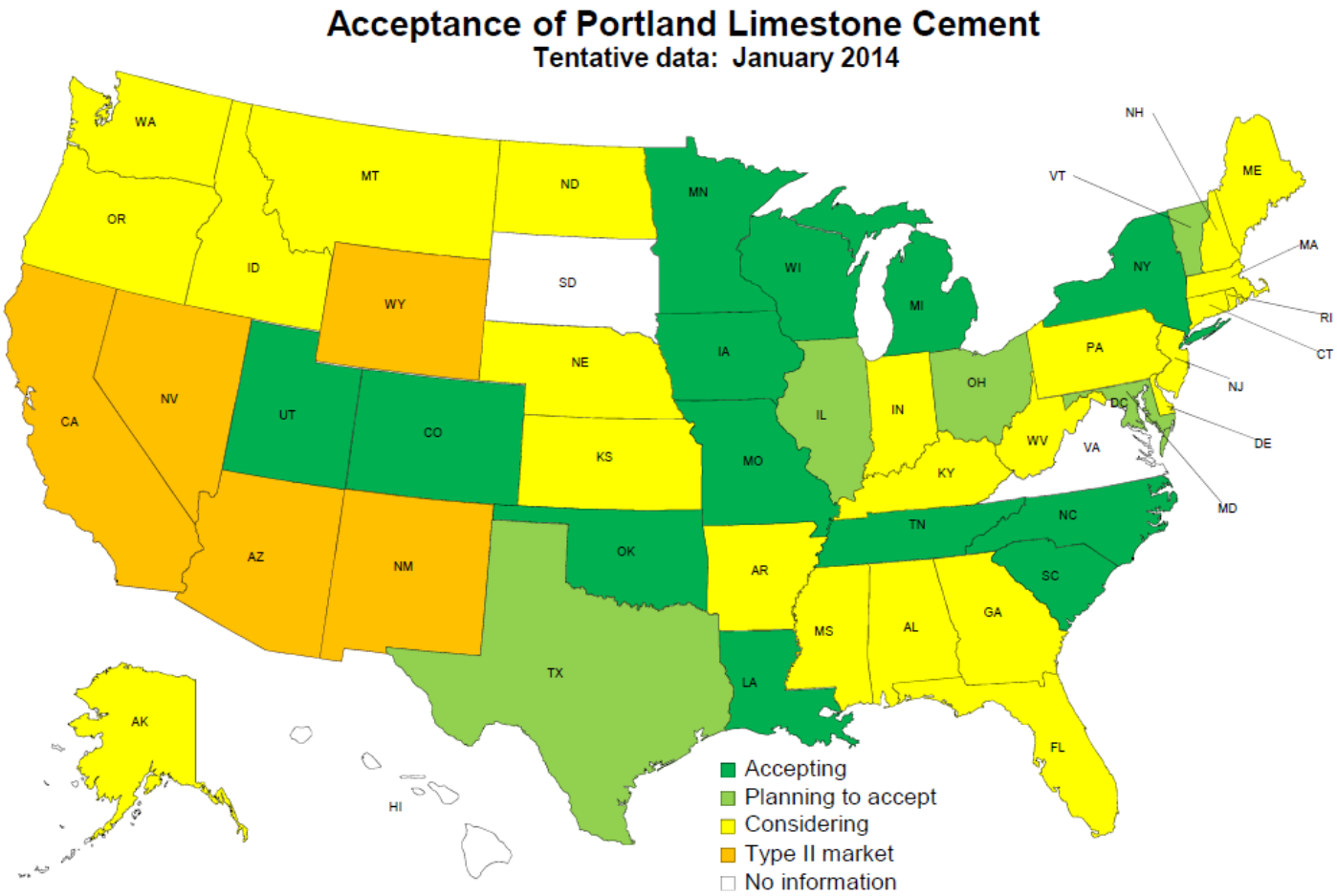
Tim Horton's Field, Hamilton, ON

- 2013-2014
- 14,000 yd^3 concrete, 30 mixes
- PLC
- Mostly exterior concrete
- Design challenges
  - Cold weather construction
  - SCC
  - LEED Silver
- Design strengths to 5000 psi

Mattamy National Cycling Center

- 2013 to 2014
- 17,000+ yd^3 concrete
- 34 mixes
- Strengths to 5000 psi for structural walls, slabs
- Leed Silver

Acceptance by State DOTs



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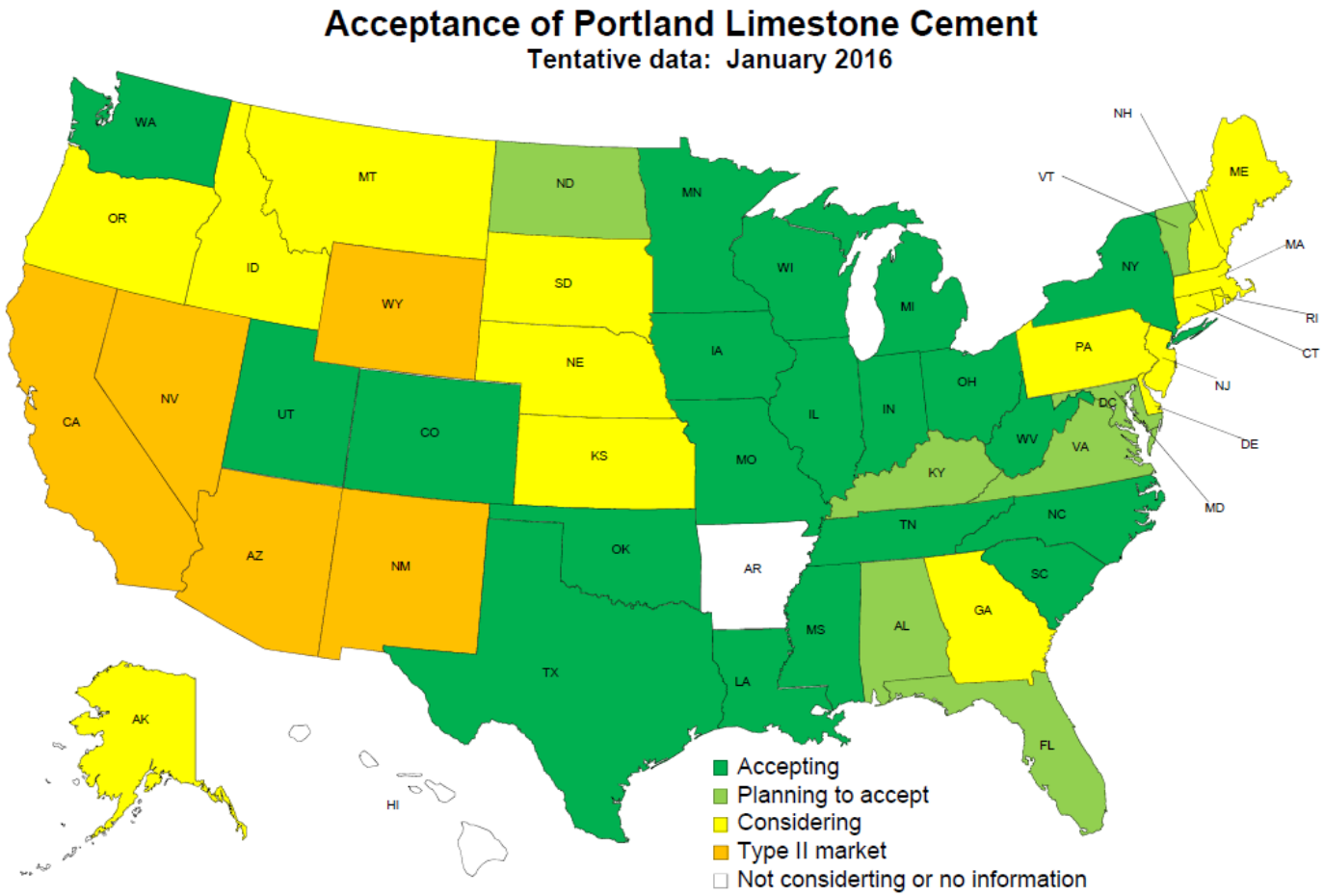

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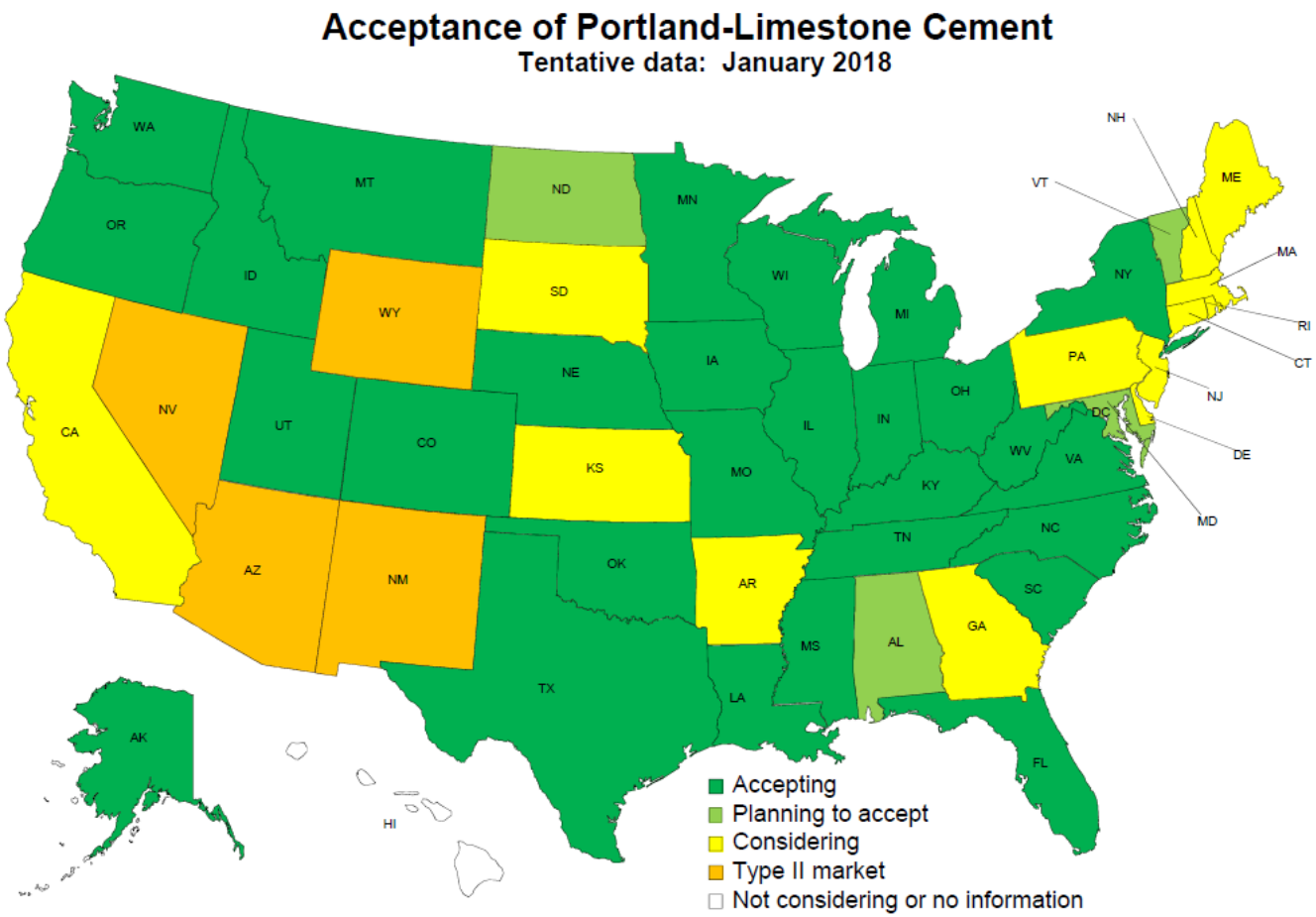

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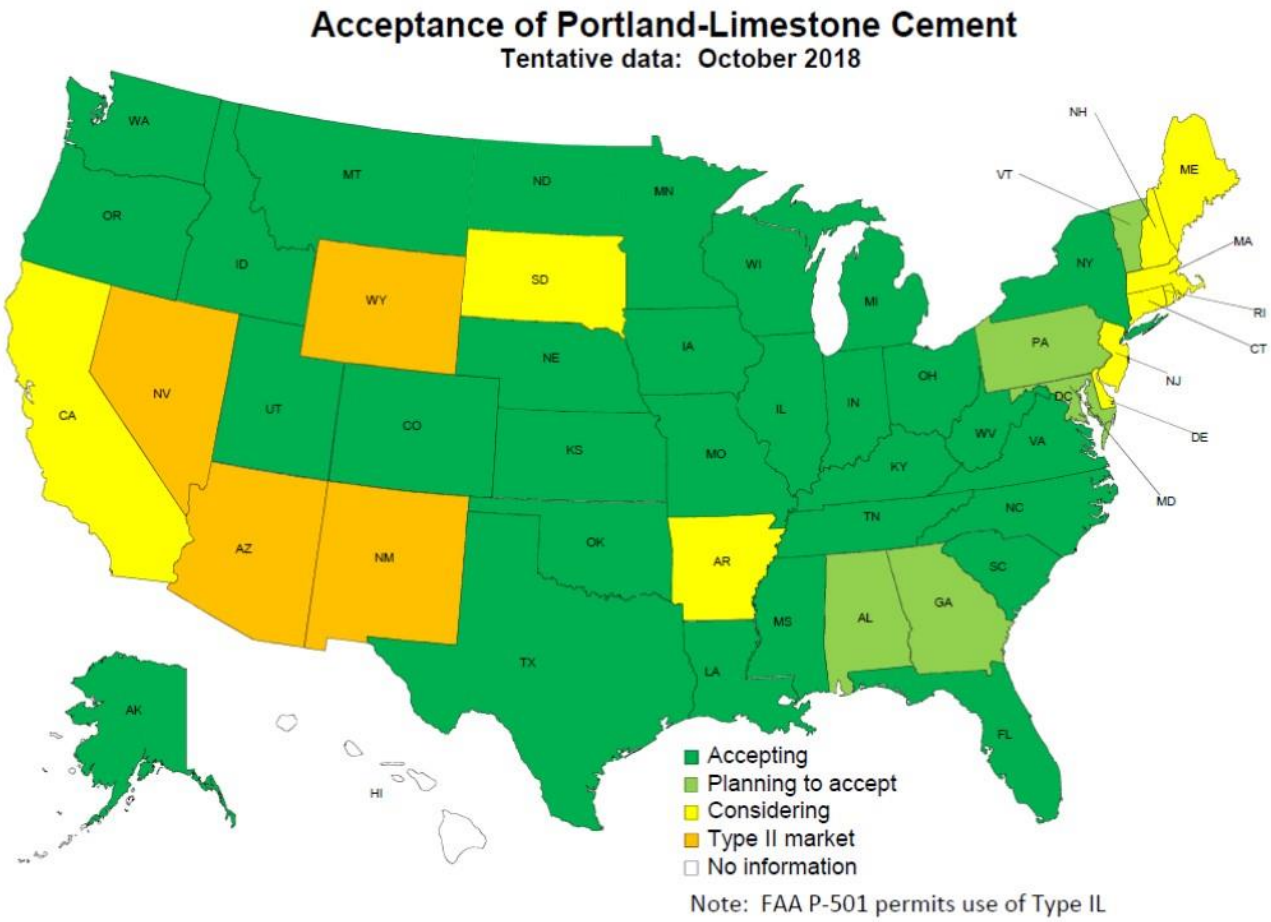

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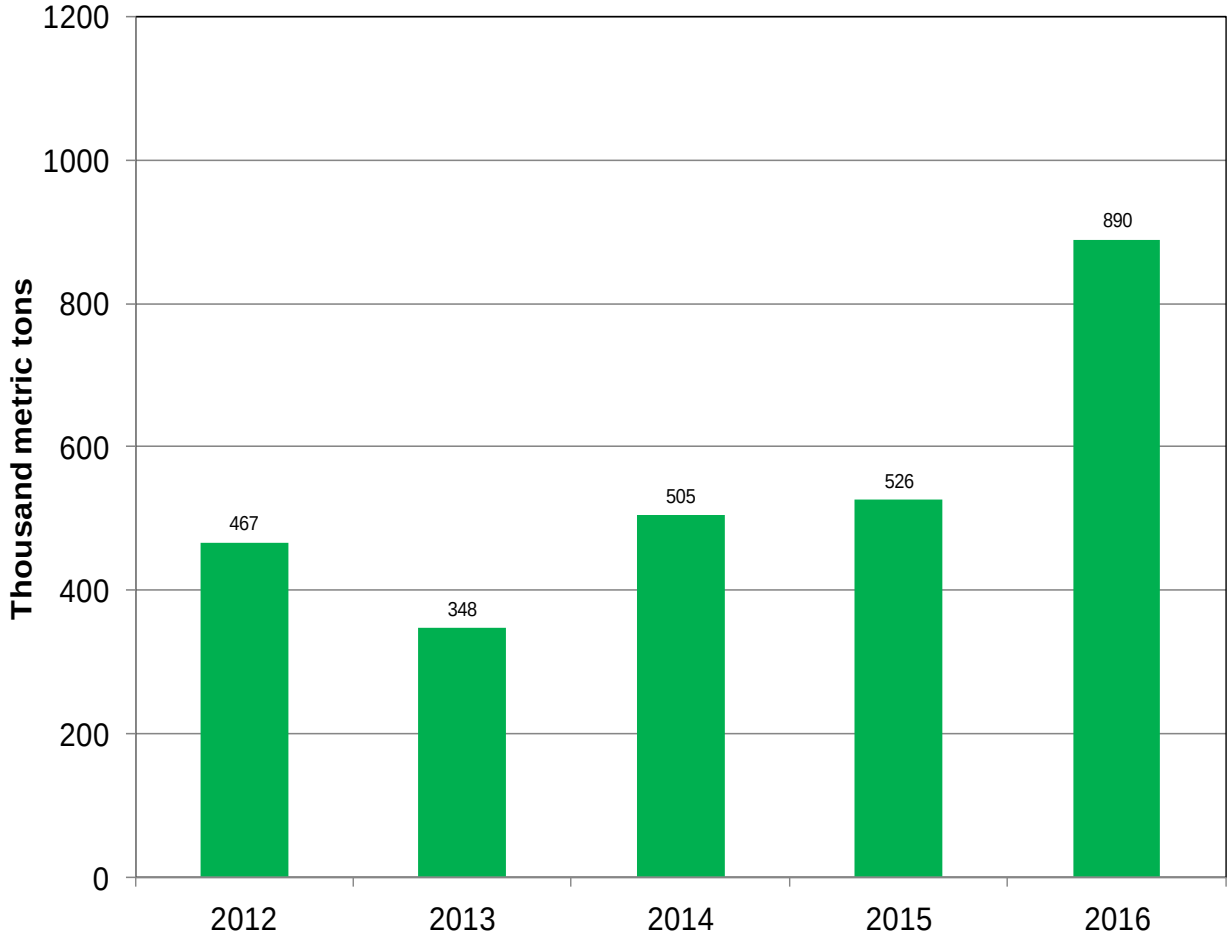
US Type IL Cement 2012 to 2016



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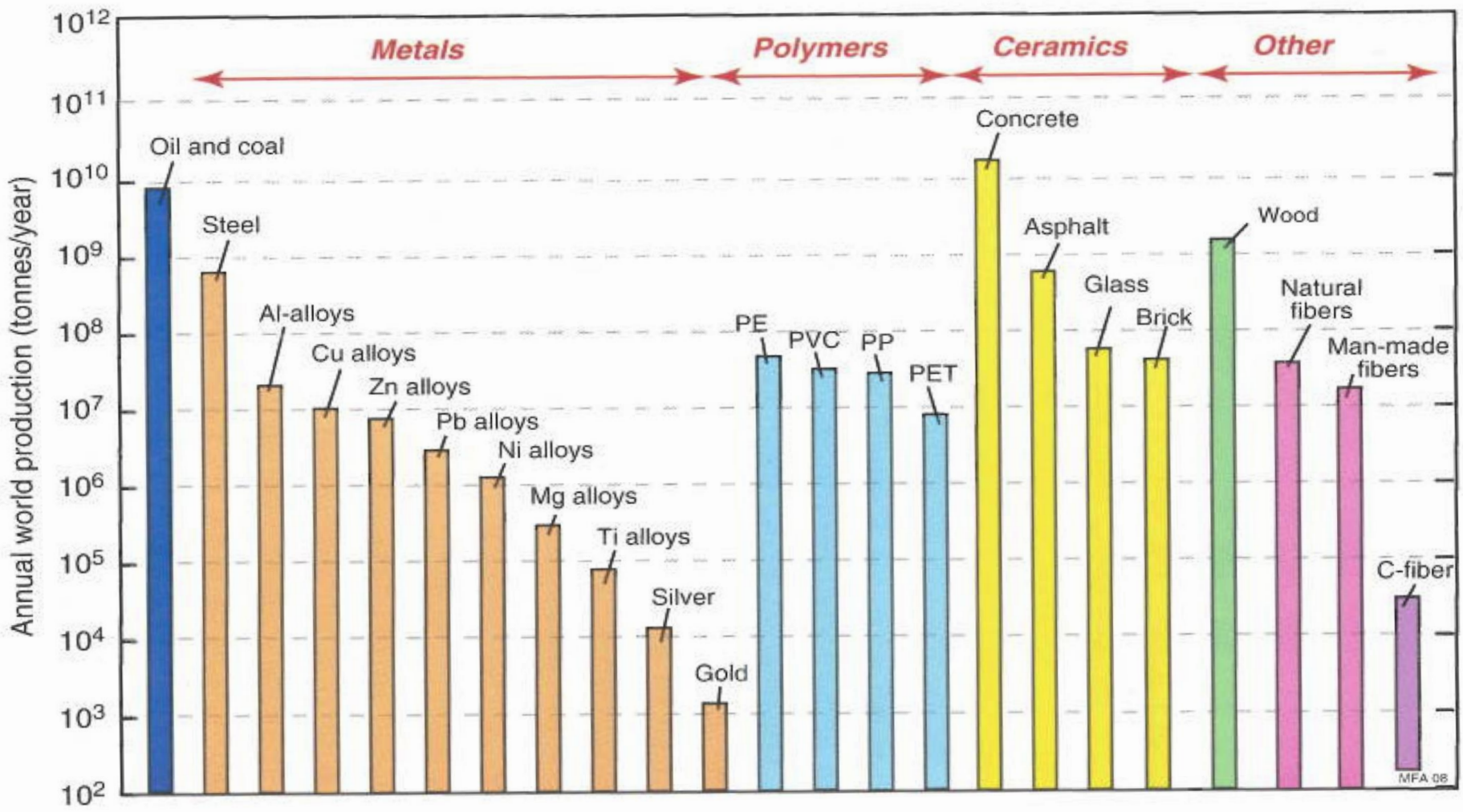
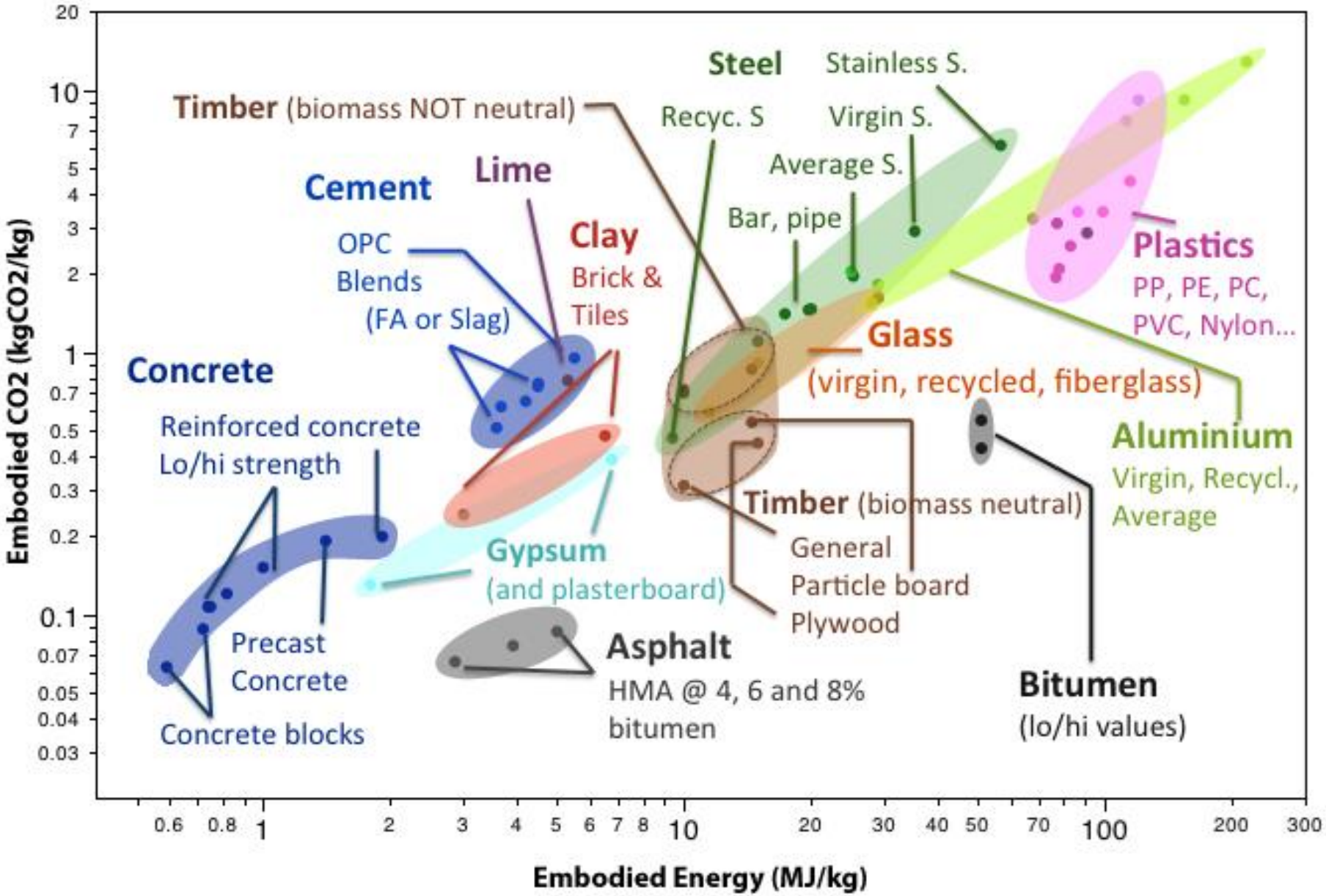
from Ashby (2009)



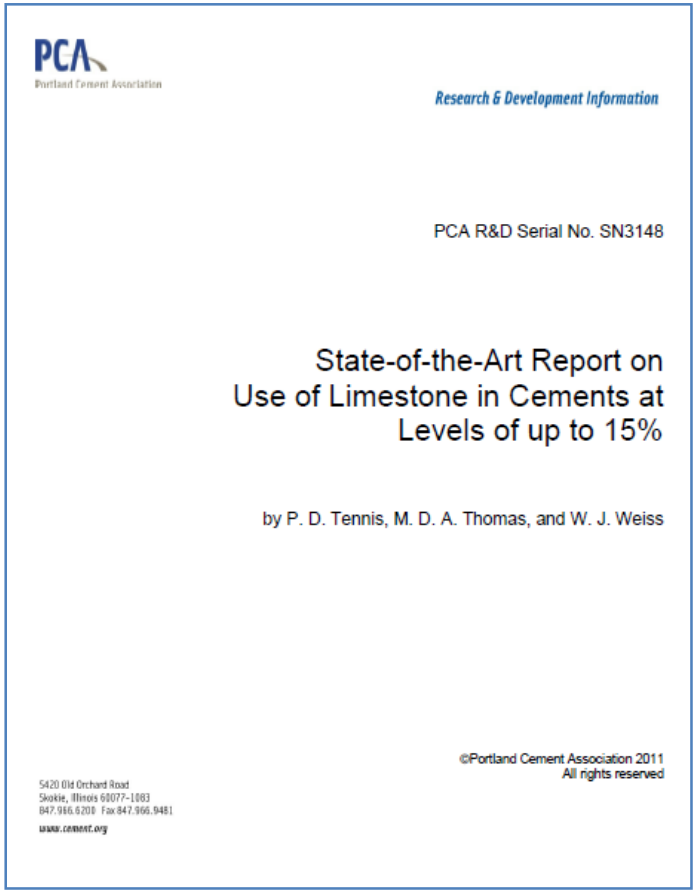

Embodied CO2 (kgCO2/kg)
Embodied Energy (MJ/kg)
Steel
Stainless S.
Recyc. S
Virgin S.
Average S.
Bar, pipe
Timber (biomass NOT neutral)
Cement
Lime
OPC
Blends
(FA or Slag)
Clay
Brick &
Tiles
Plastics
PP, PE, PC,
PVC, Nylon...
Glass
(virgin, recycled, fiberglass)
Concrete
Reinforced concrete
Lo/hi strength
Aluminium
Virgin, Recycl.,
Average
Timber (biomass neutral)
General
Particle board
Plywood
Gypsum
(and plasterboard)
Precast
Concrete
Concrete blocks
Asphalt
HMA @ 4, 6 and 8%
bitumen
Bitumen
(lo/hi values)

Summary

Portland-Limestone Cement

- Has a proven track record
  - More than 75 countries around the world
  - In Europe since 1960s
  - In Canada many condos, industrial slabs and Pam-Am Games sporting facilities since 2010 successfully
- Reduces GHG emissions up to 10%
- Produces concrete with a comparable level of strength and durability as that produced with regular portland cement

Additional information



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Research & Development Information

PCA R&D Serial No. SN3148

State-of-the-Art Report on
Use of Limestone in Cements at
Levels of up to 15%

by P. D. Tennis, M. D. A. Thomas, and W. J. Weiss

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Skokie, Illinois 60077-1083
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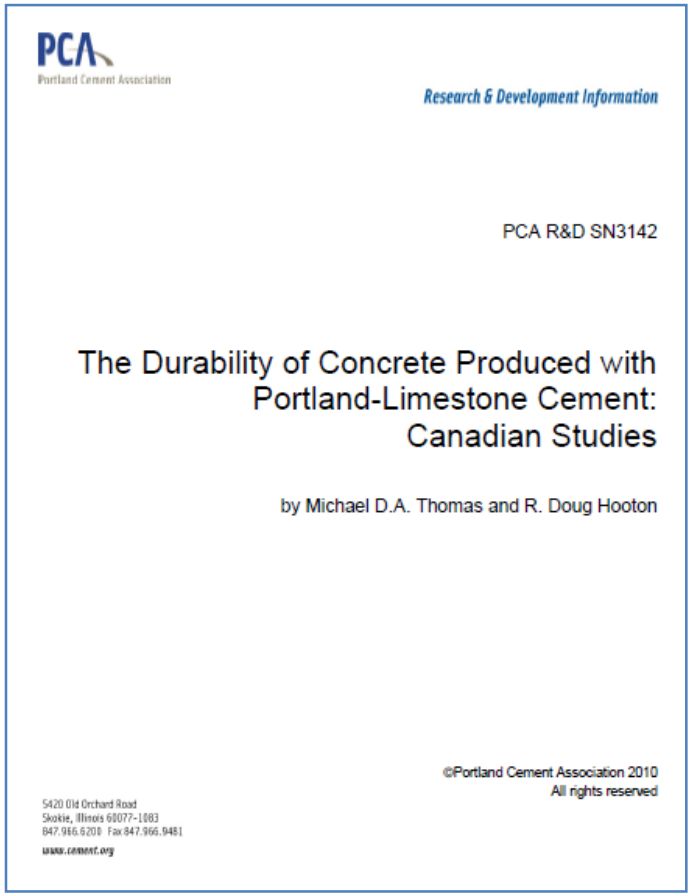

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Research & Development Information

PCA R&D SN3142

The Durability of Concrete Produced with
Portland-Limestone Cement:
Canadian Studies

by Michael D.A. Thomas and R. Doug Hooton

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www.cement.org/pdf_files/SN3148.pdf

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