UNIVERSITY OF SÃO PAULO
ESCOLA POLITÉCNICA

Sustainability and Development in the Cement Industrial Complex

Vanderley M. John
Rafael G Pileggi

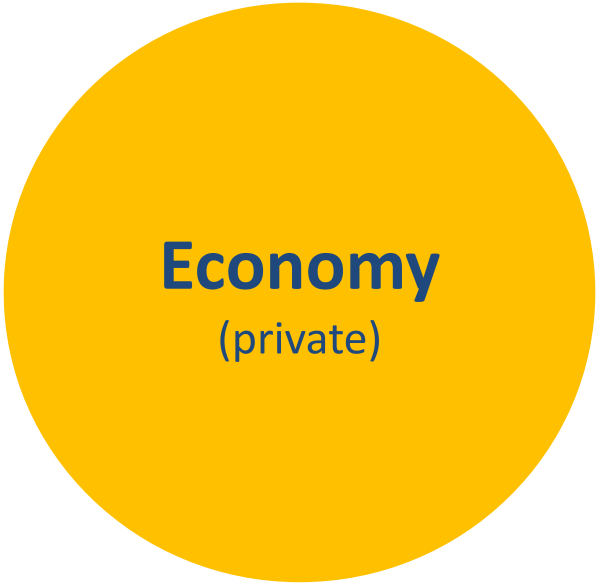
CBC
6º CONGRESSO BRASILEIRO DO CIMENTO

For any given problem

(almost) infinite number of

technical solutions

Economically viable solutions



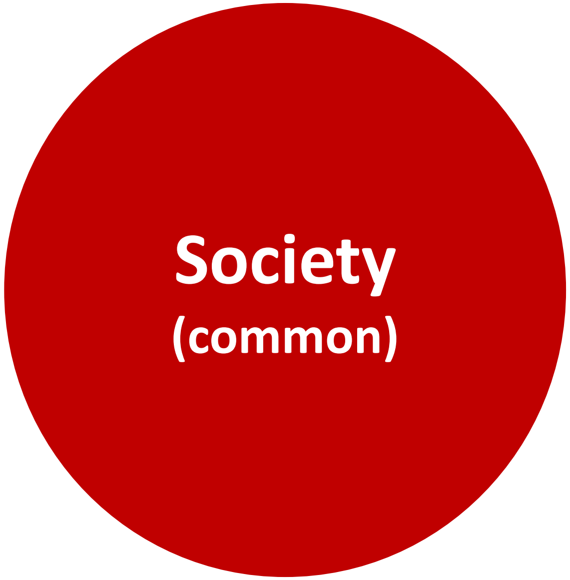
technical solutions

Green solutions

technical solutions

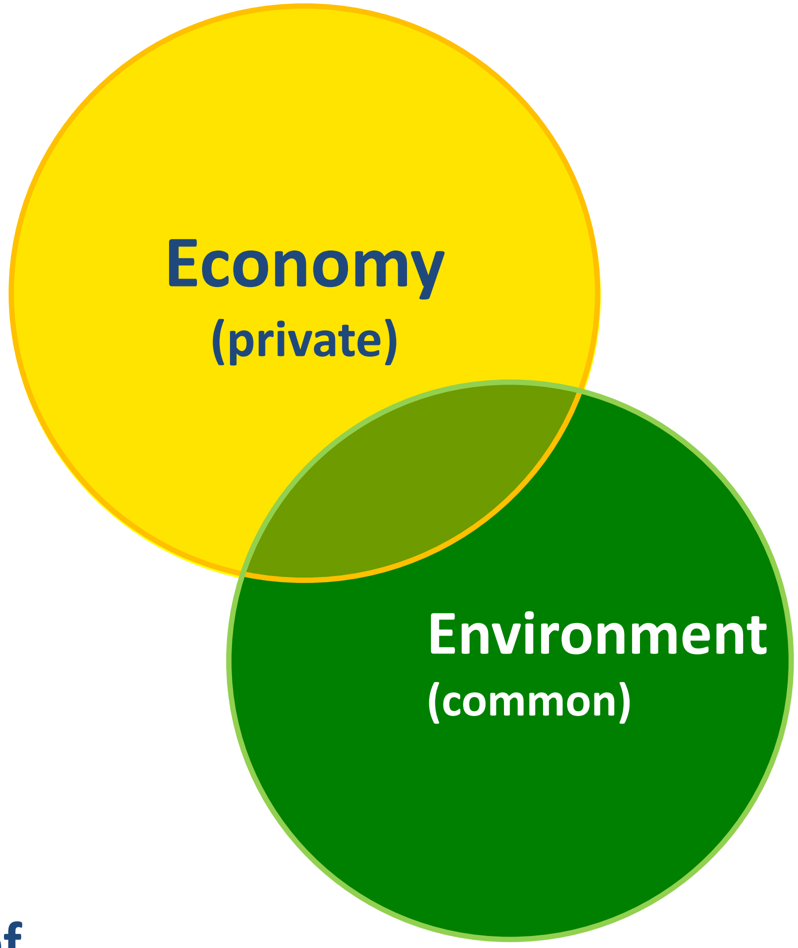
Tragedy of the commons
G Hardin

Socially Responsible Solutions



technical solutions

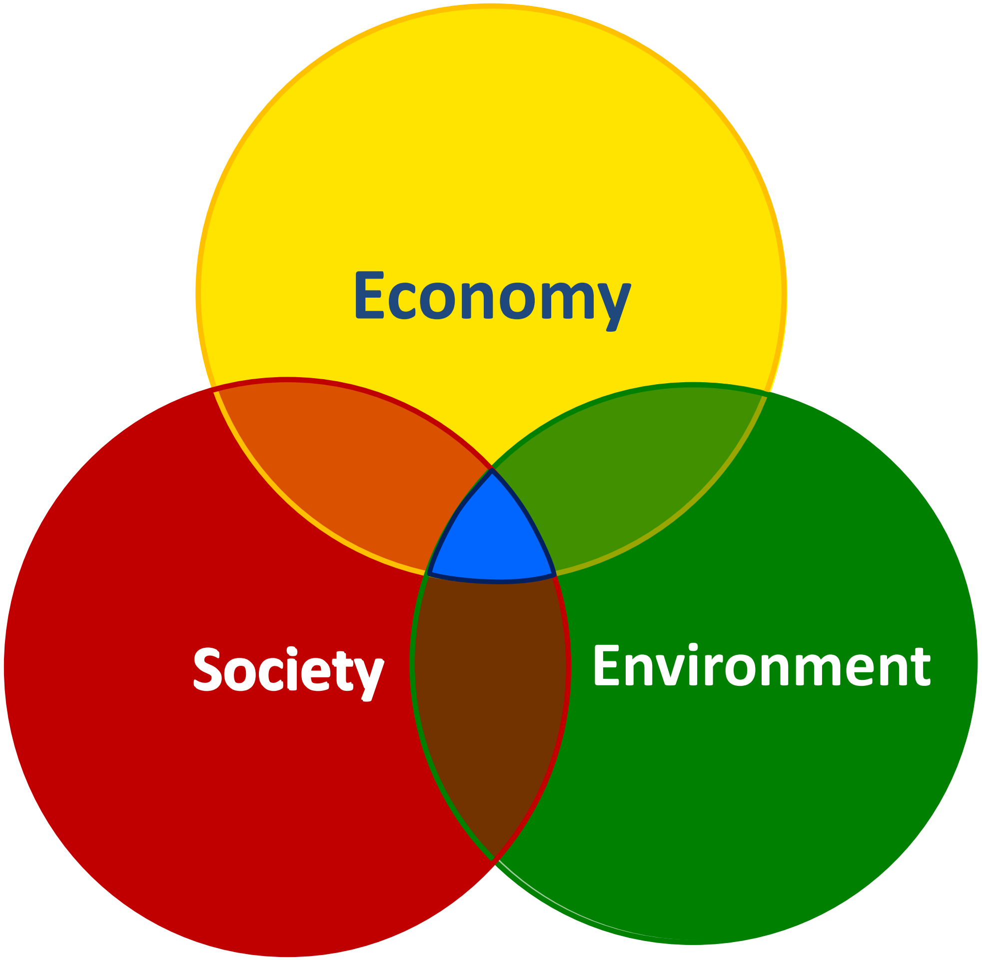
Eco-Efficient Solutions



almost) infinite number of

technical solutions

Sustainable Solutions



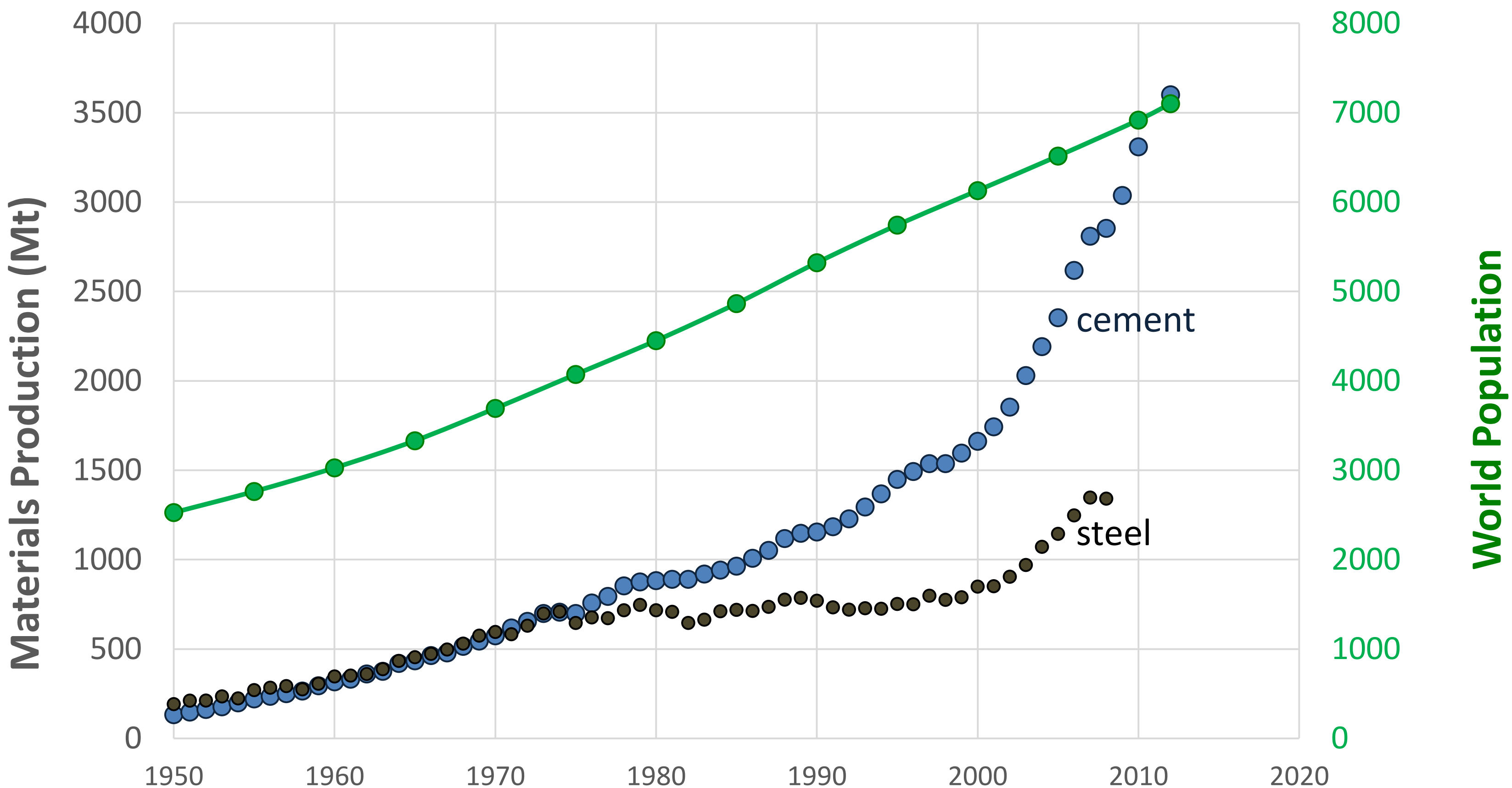
technical solutions

Sustainable Solutions

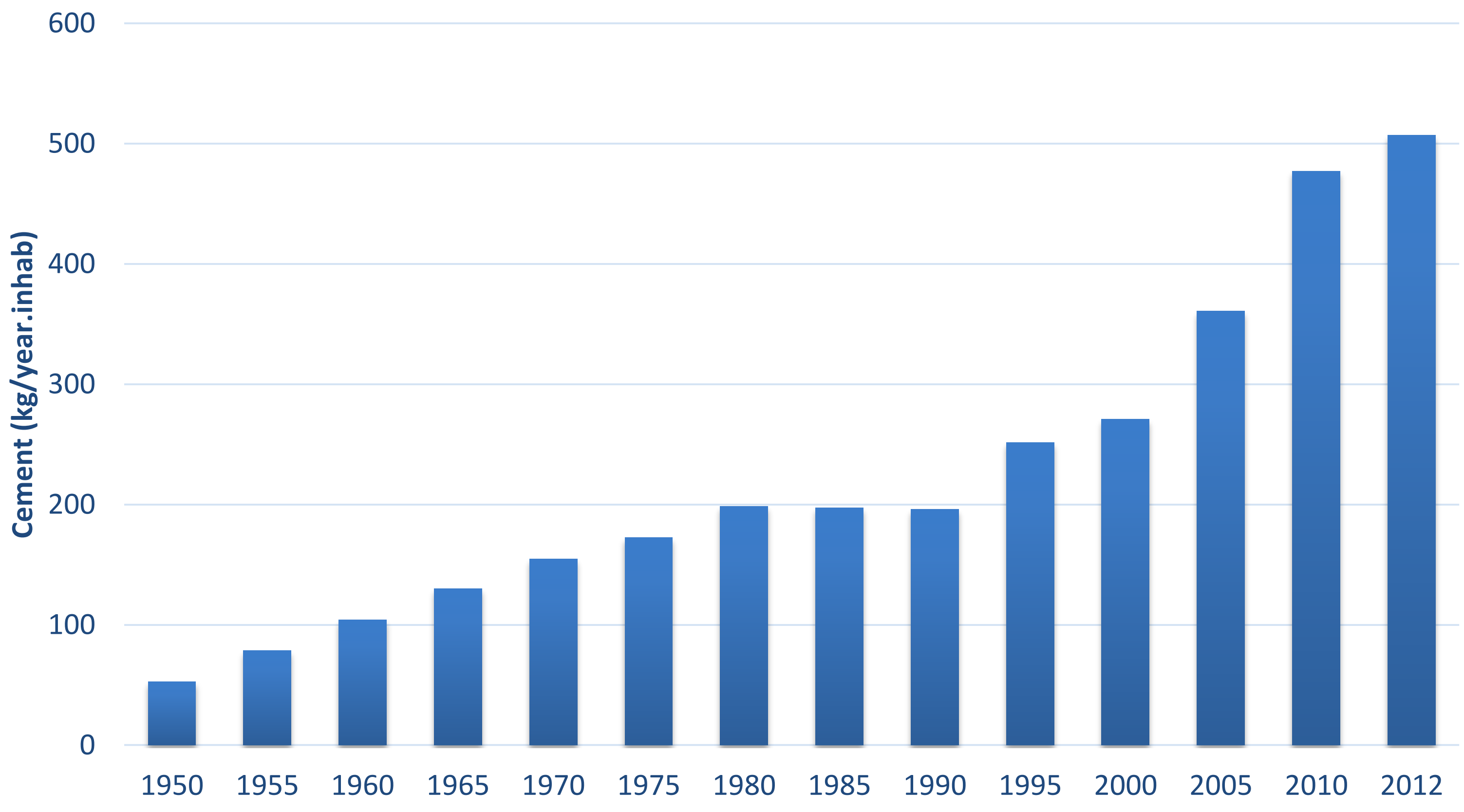
solve the problems,
whitin the budget,
making society happy.

are exceptionally rare!

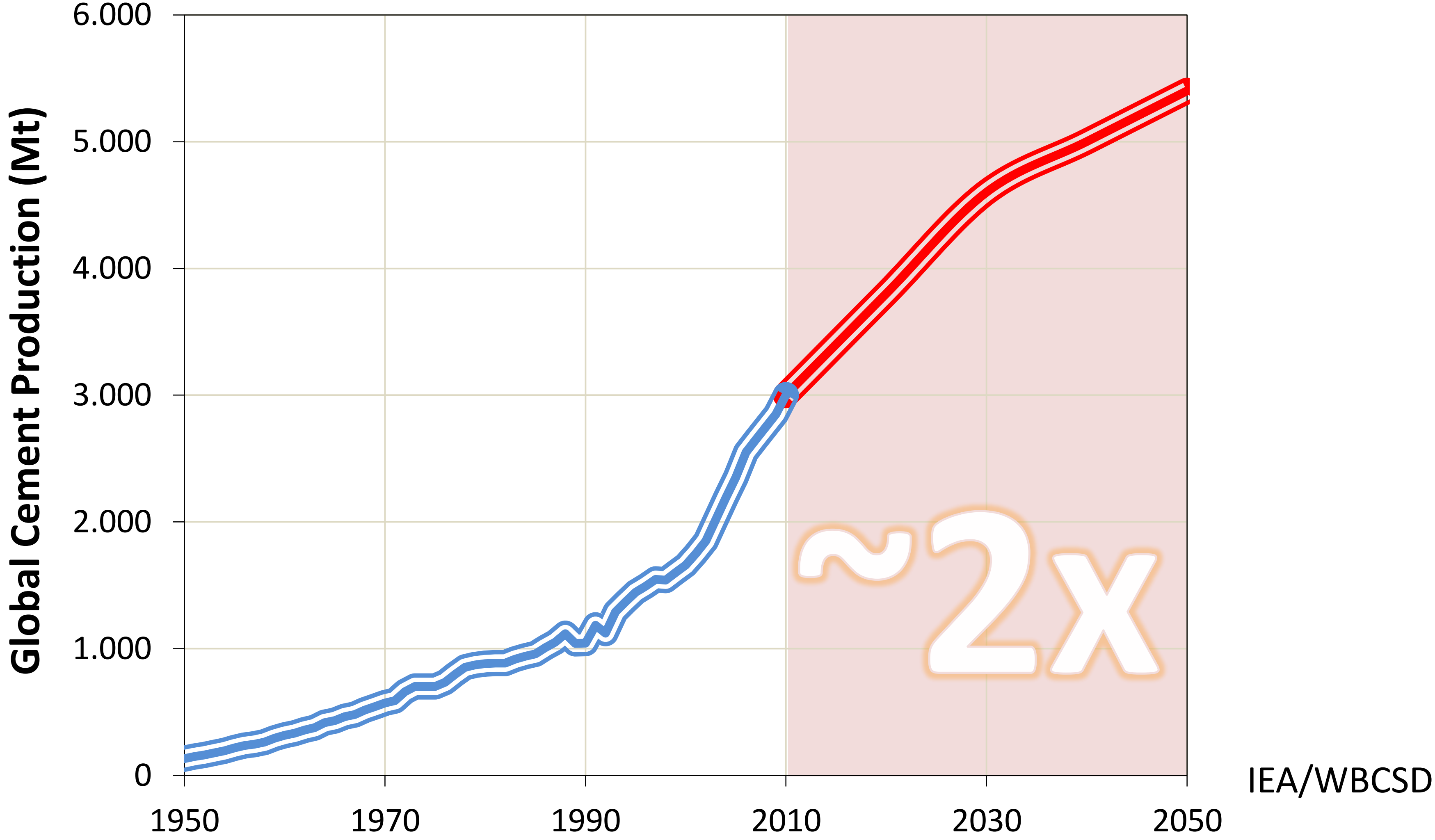
A Superb Global Cement Market



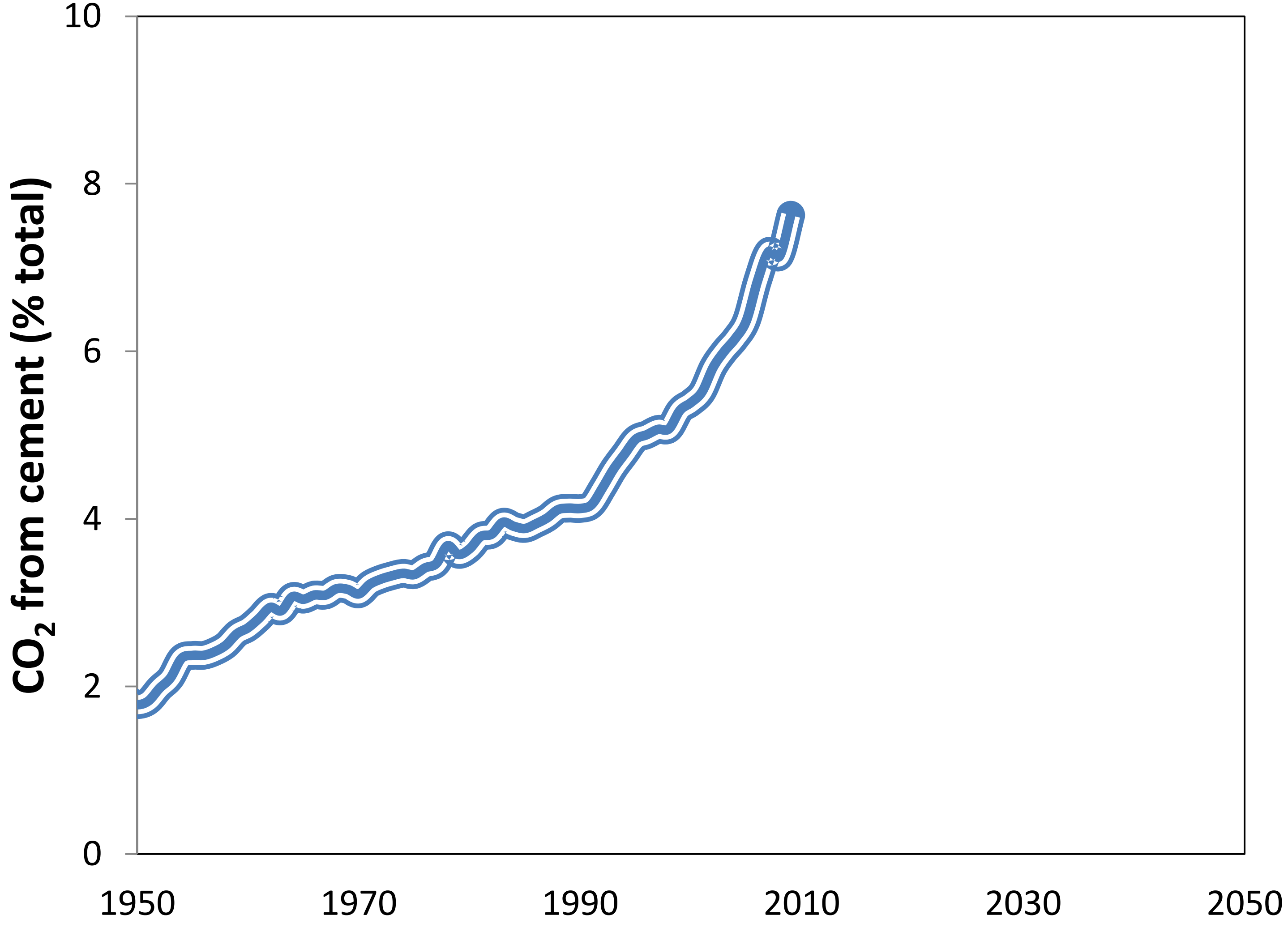
A Superb Global Cement Market



Cement Demand Forecast

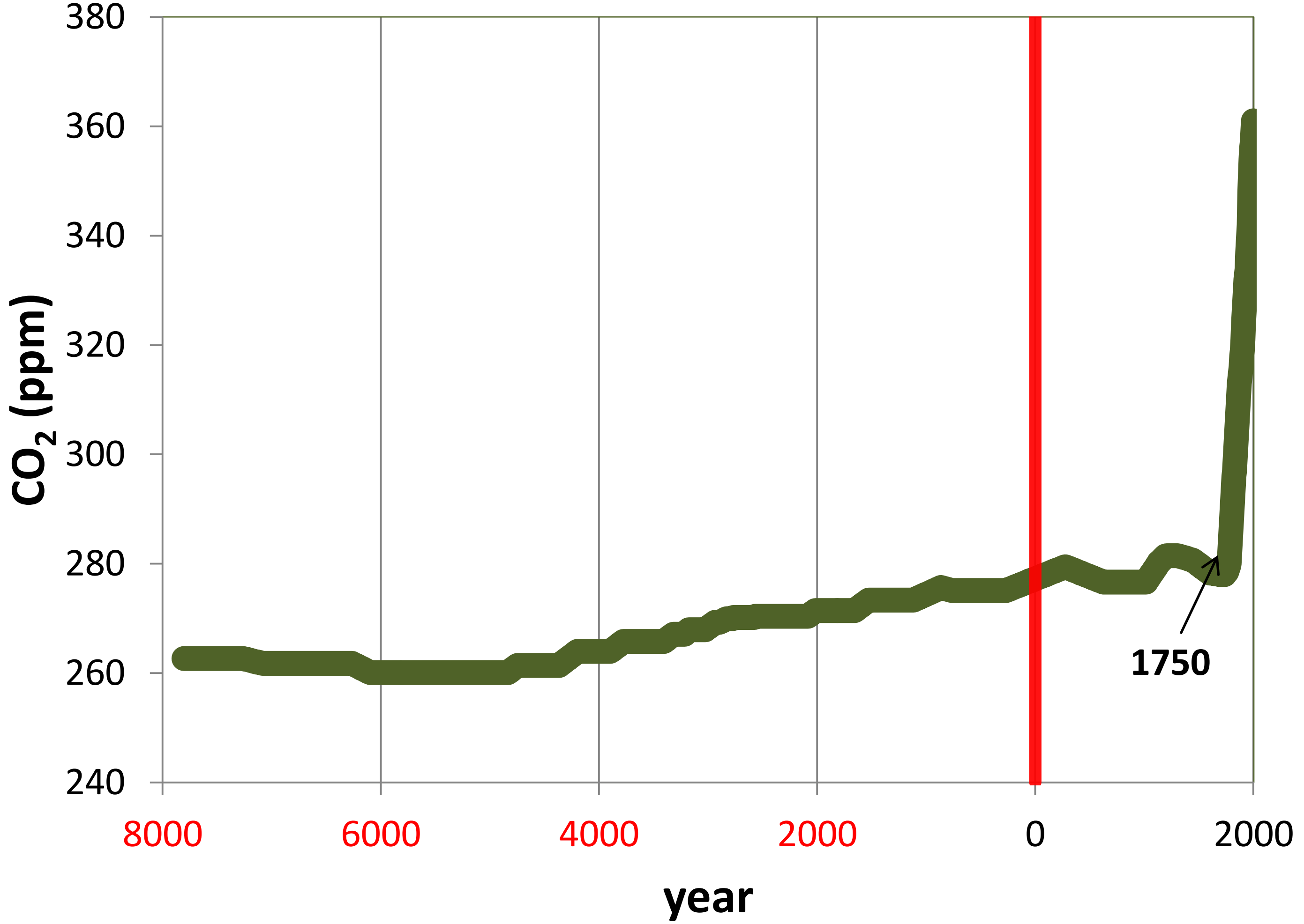


One environmental side-effect



A partir de Bonde, T. Global CO2 Emissions from Fossil-Fuel Burning Cement Manufacture, and Gas Flaring: 1751-2009 LBL, Sept 2012

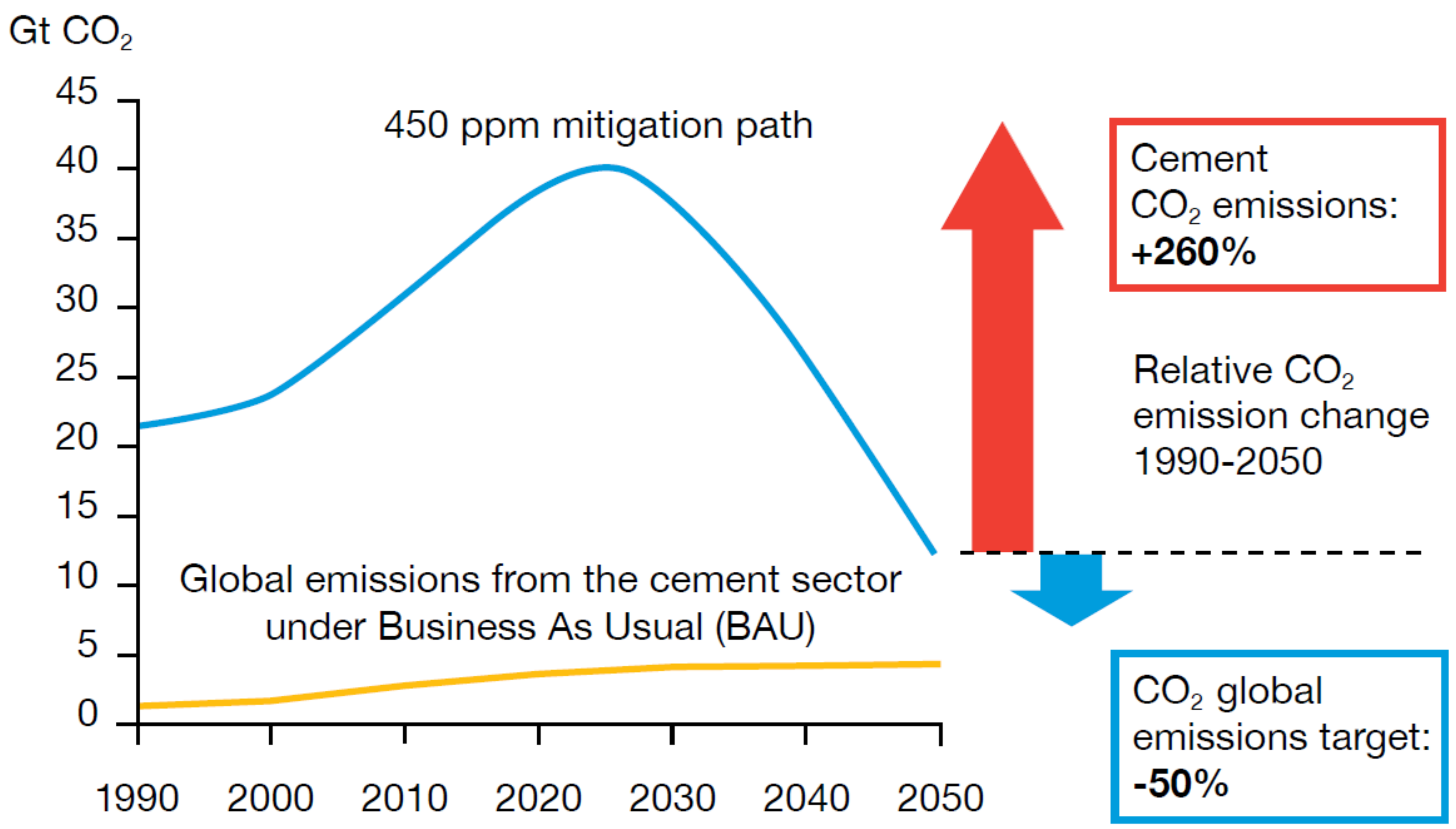
CO_2 Concentration



IPCC - Climate Change 2007: The Physical Science Basis - Summary for Policymakers http://www.ipcc.ch/

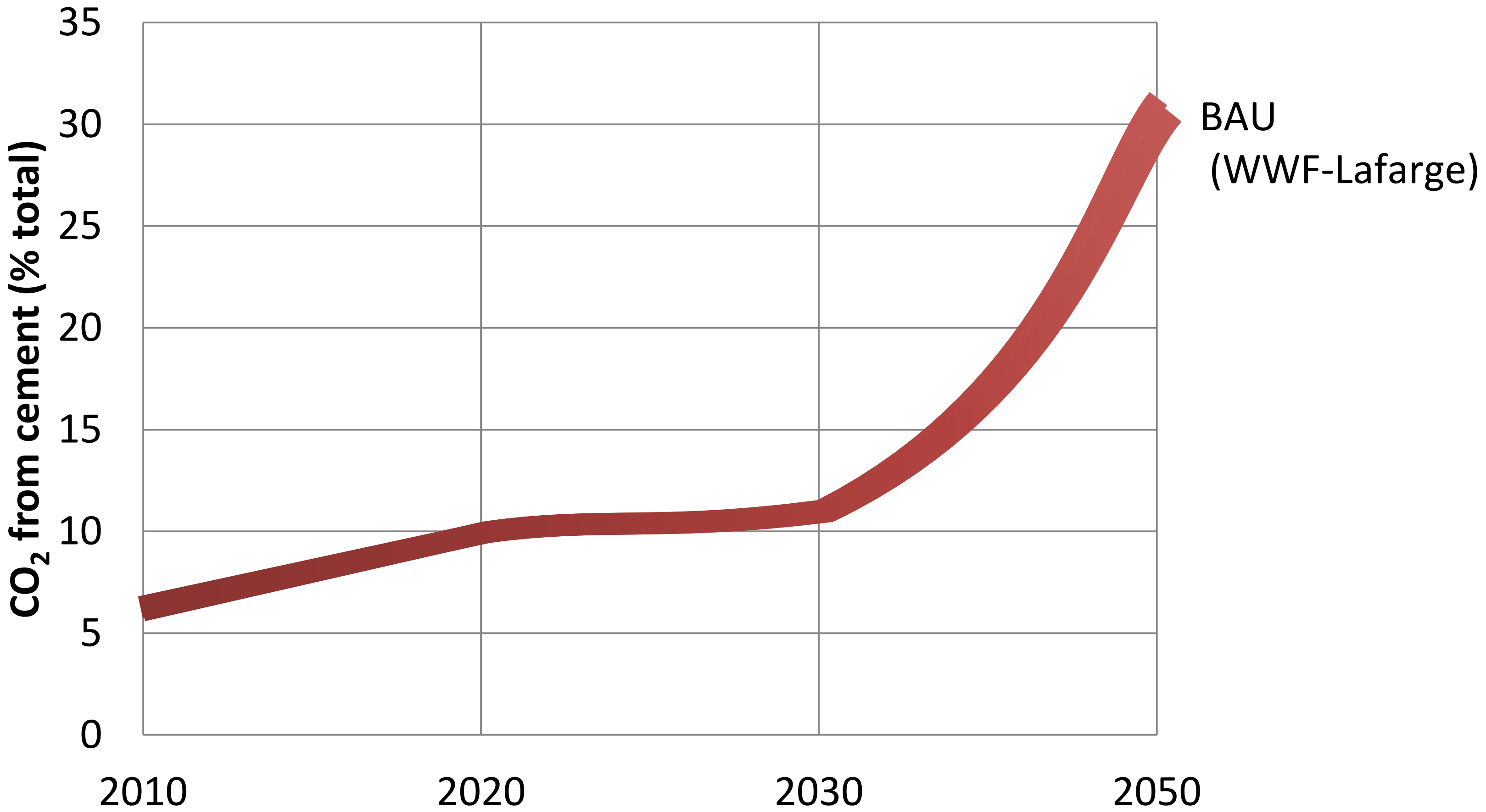

The Economist
SPECIAL REPORT
THE ARCTIC
June 16th 2012
The melting north

CO_2 Emission Forecast



A blueprint for a climate friendly cement industry. WWF-Lafarge 2008

CO_2 Emissions Forecast

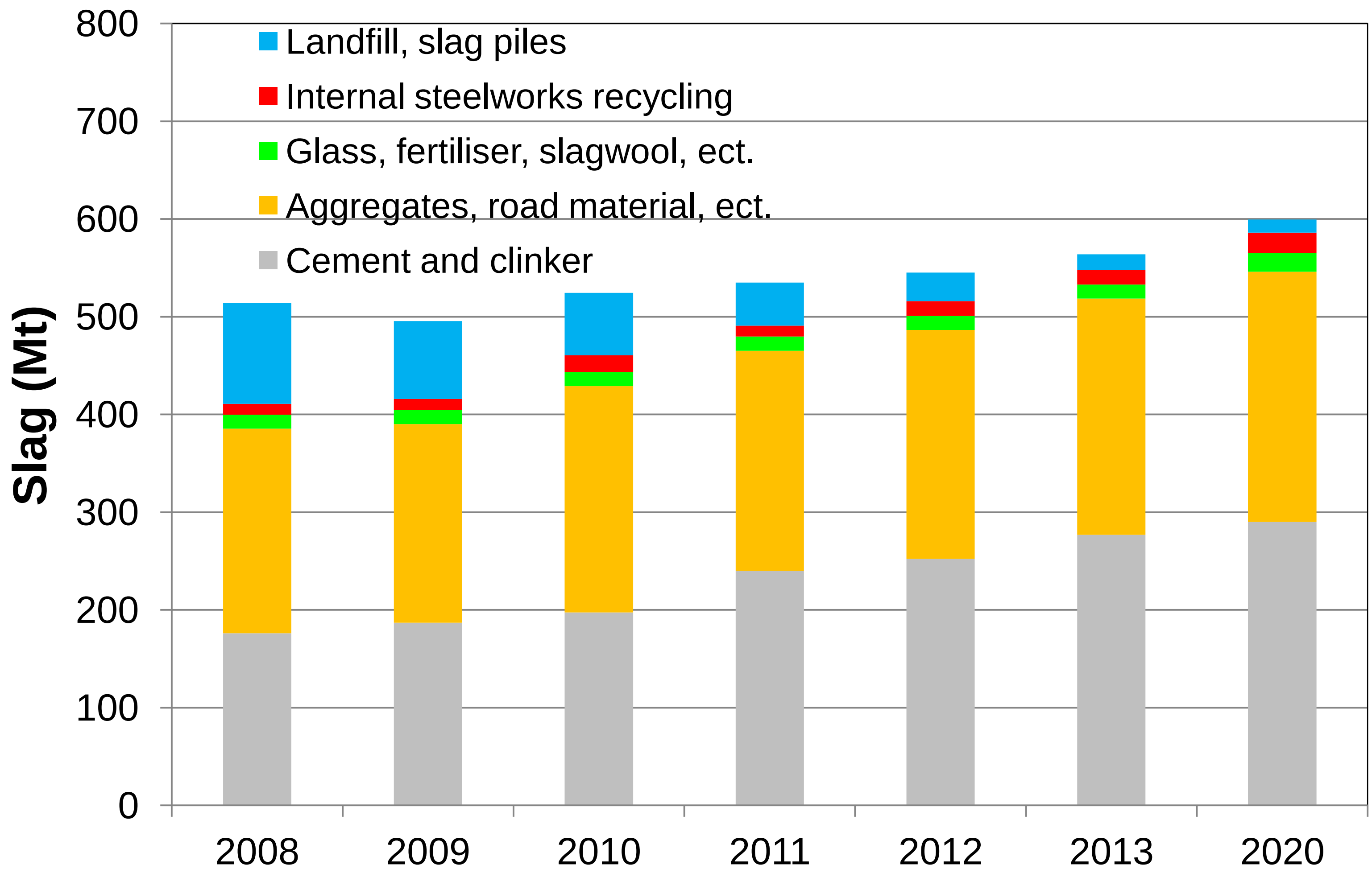


A blueprint for a climate friendly cement industry. WWF-Lafarge 2008

High CO_2 Emissions forecast: one reason

SCM AVAILABILITY

Ferrous slag generation



(Smiters Pira, 2011).

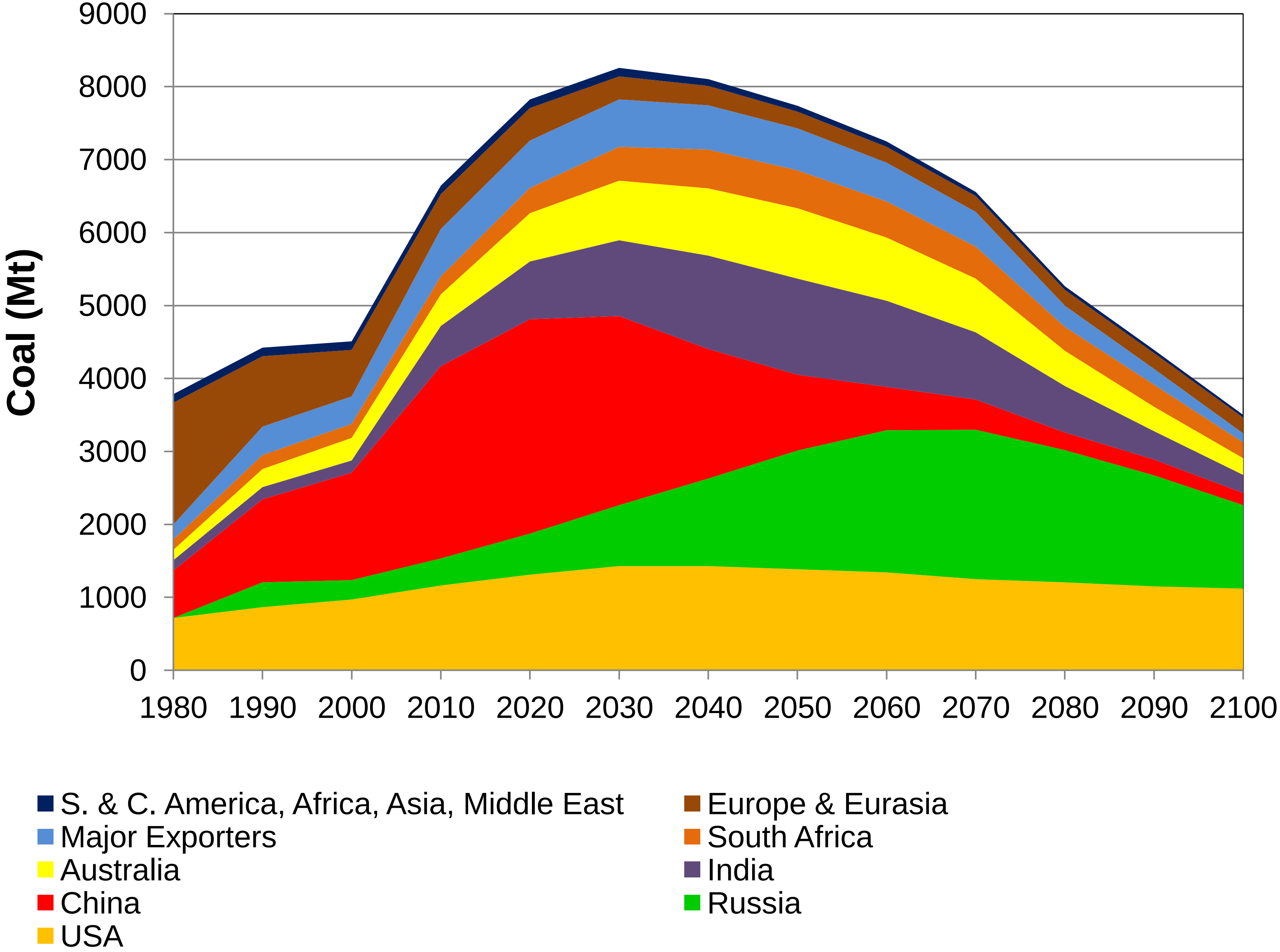
Blast Furnace Slag in Cement

Year	BFS (Mt)	Cement (Mt)	BFS (%)
2010	200	3.000	**6,5**
2020	280	3.800	**7,4**

All slag in cement ~ 16%

Production is growing in China (~60% of total).

Mineral Coal Consumption

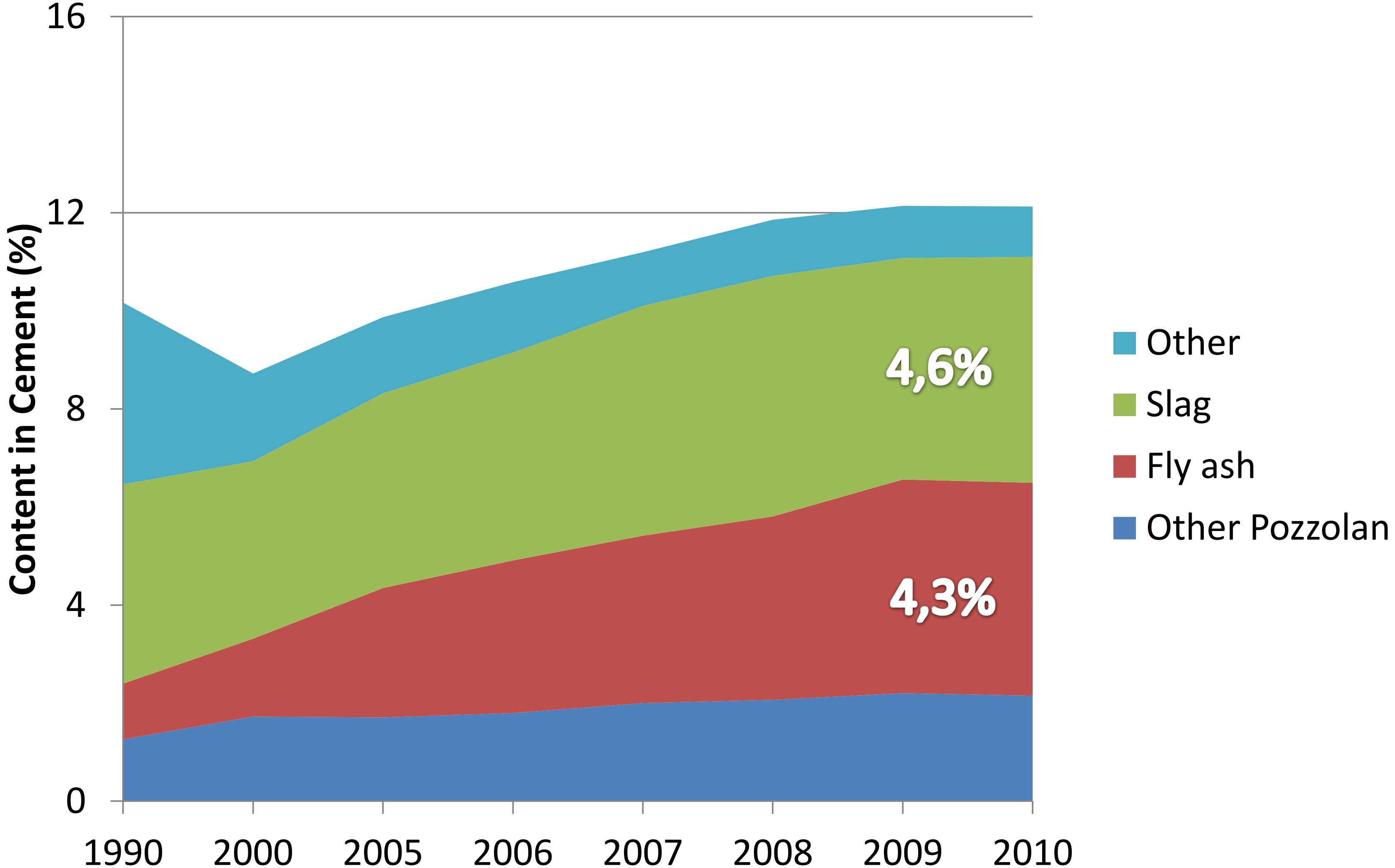


Fly ash in cement

- Total ash content ~11% (ACAA 2011)
- Fly ash content ~8,50%

- **WBCSD 2020 - 14% cement production**
  - 500 Mt
  - 80% recycling rate
- **Decrease is projected after 2030!**

SCM in cement - WBCS CSI Data



GNR (2010 data)

Slag+ Fly ash Availability

SCM	2010	2020		2050
	Effective CSI	Most Probable	Maximum Possible	
BFS	4,6%	7,5%	14%	?
Fly ash	4,3%	14%	25%	Decrease
Total	**8,9%**	**21,5%**	**39%**	**?**

- **Base scenario: WBCSD (2009)**
- **Maximum possible:**
  - All slags and ashes recycled in cement

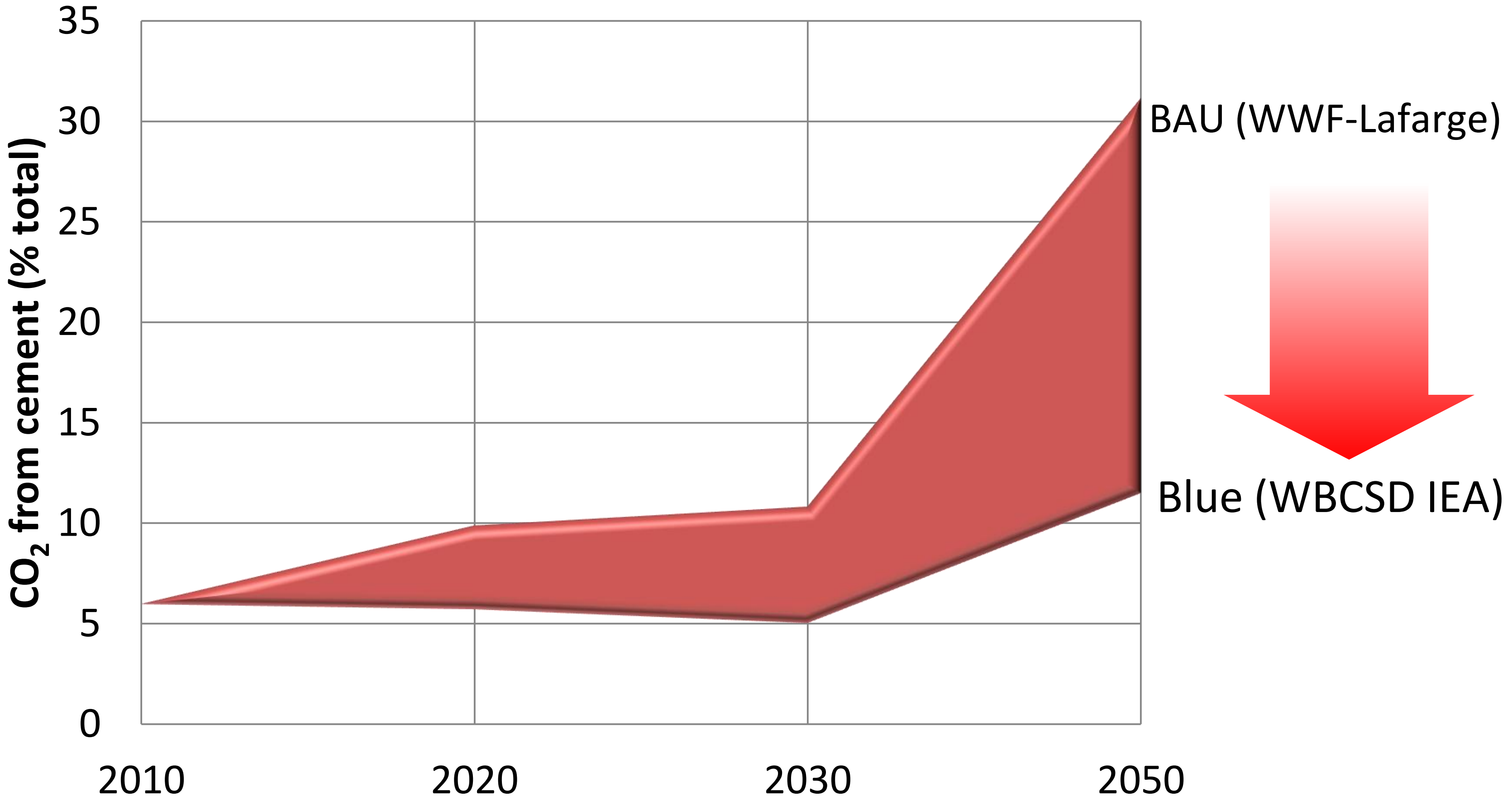
Fly ash and slag will not be enough!

- Local availability
- Global shortage
- CO_2 allocation reduces benefit

WBCSD & IEA Cement Technology Roadmap 2009

CEMENT INDUSTRY STRATEGIC PLANNING

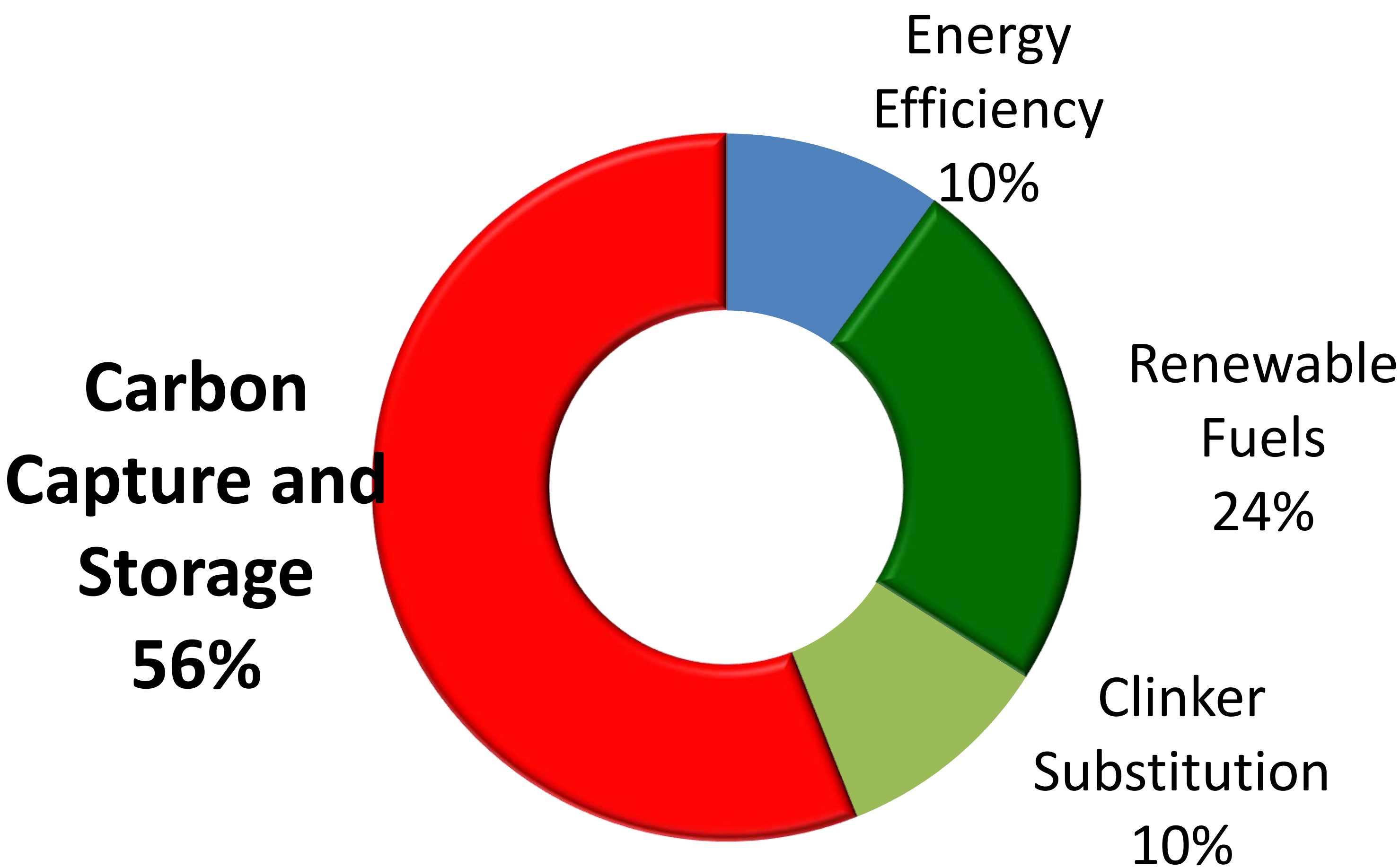
CO_2 Emissions Forecast



WBCSD & IEA Cement Technology Roadmap 2009

A blueprint for a climate friendly cement industry. WWF-Lafarge 2008

WBCSD/IEA CO_2 MITIGATION



WBCSD & IEA Cement Technology Roadmap 2009

COST WBCSD/IEA CO_2 MITIGATION

US $354 a 843 billion

CCS ~80%

WBCSD & IEA Cement Technology Roadmap 2009

Carbon Capture and Storage Cost

USD $40–170/t CO_2

Cement cost will increase

WBCSD & IEA Cement Technology Roadmap 2009

Economic Viability

Cement will loose competitiveness!

Heavy investment.

Higher operational costs.

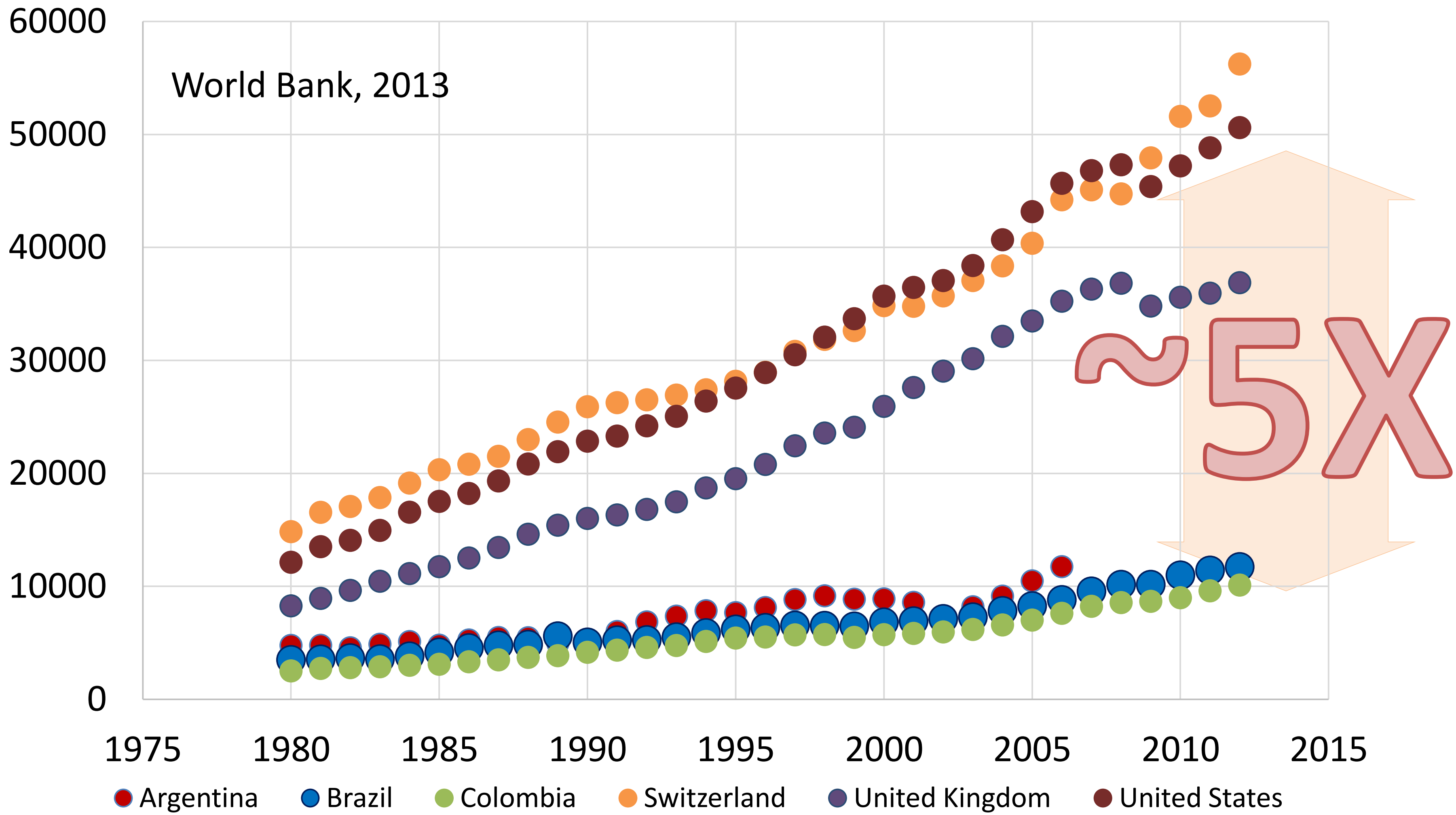
Social equity

expensive cement is a

social problem

for developing countries

Gross National Income per capita, PPP ($)

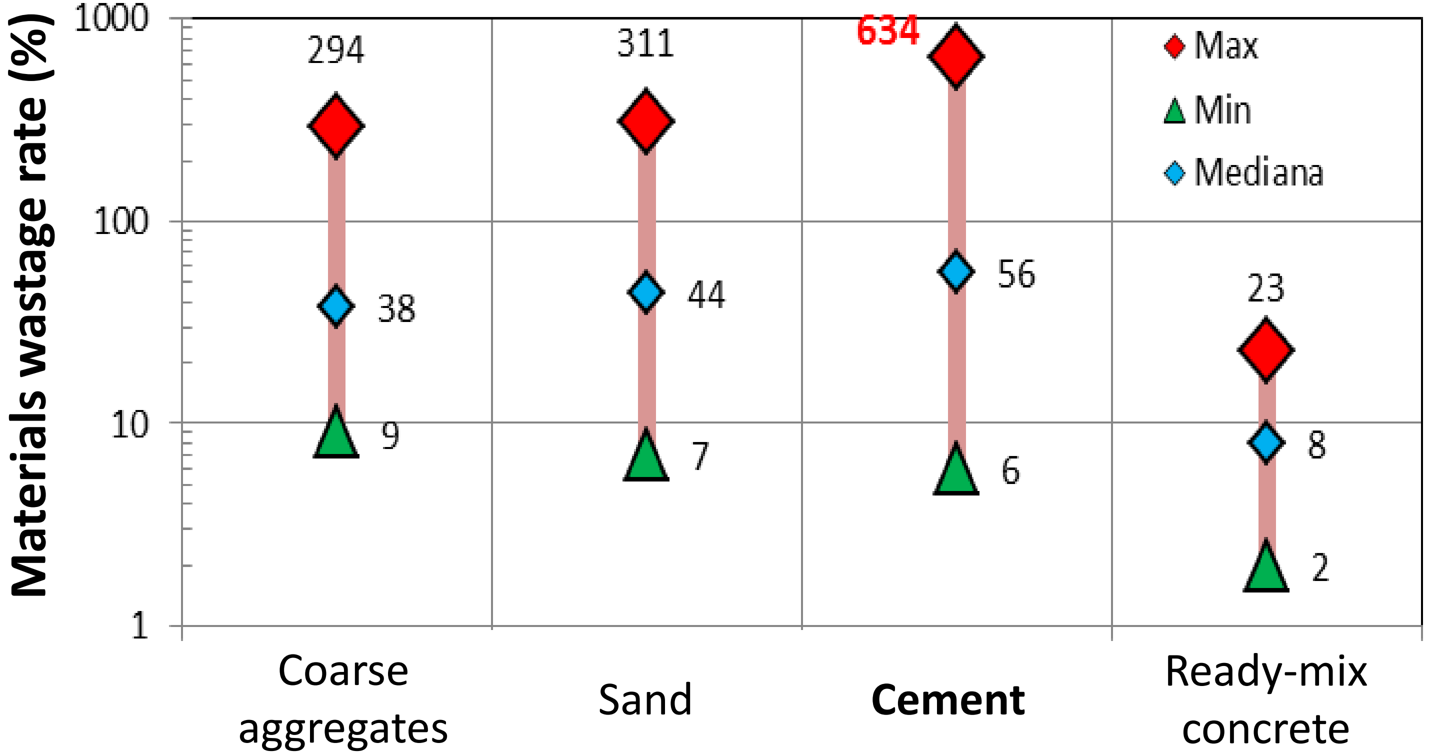


WE NEED A SUSTAINABLE SOLUTION!

Option:
Increase binder use efficiency

- **Produce more cement-based products with the same amount of binder.**

Wastage rate of materials at building sites (Brazil)



Low Binder Content

Low content of reactive, high-temperature, scarce material (Clinker, Slag, pozzolans) and **high content of inert** abundant materials**.**

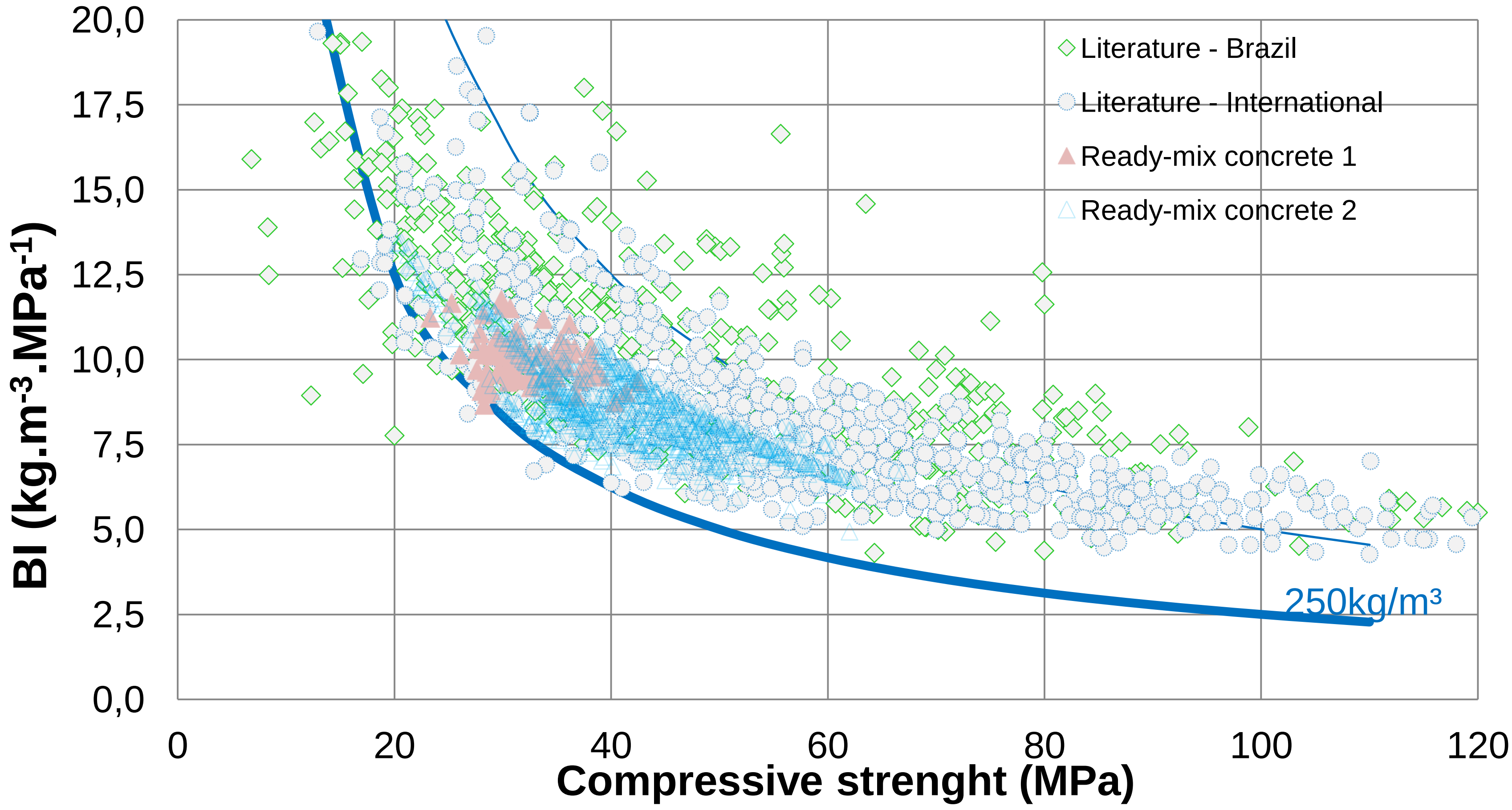
Binder Intensity

$$BI = \frac{\text{Binder content (kg/m}^3\text{)}}{\text{Performance Indicator}}$$

- **Binder: reactive materials**
  - clinker, gypsum, slag, pozzolans
  - No limestone filler
- **Performance:**
  - Compressive strength
  - CO_2 footprint
  - ...

Binder Intensity ($kg.m^{-3}.MPa^{-1}$)

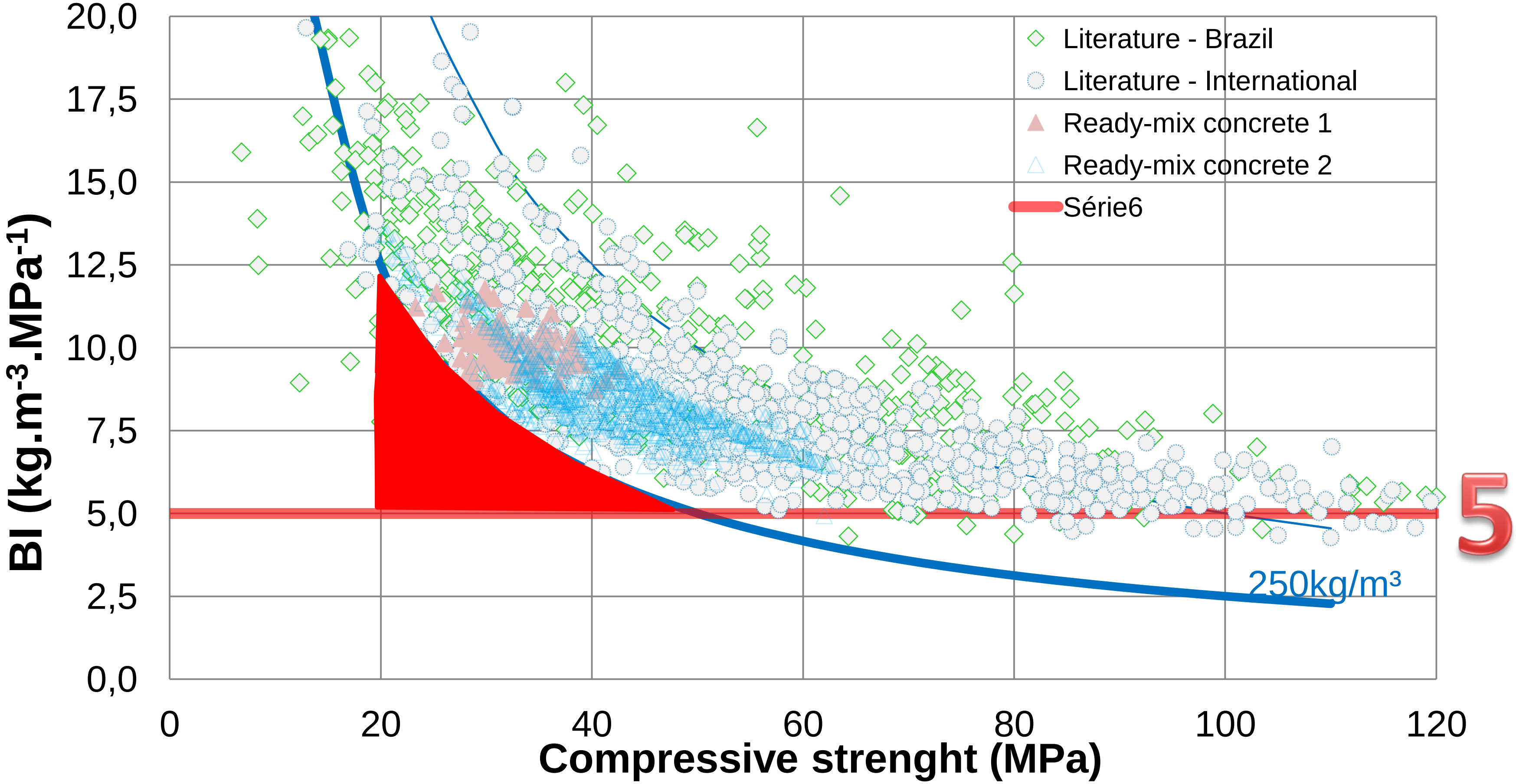
Benchmark 29 Countries



DAMINELI, B. L. KEMEID, F. M. AGUIAR, P. S.; JOHN, VANDERLEY M. Measuring the eco-efficiency of cement use. **Cement and Concrete Composites**, v. 32, n. 8, p. 555-562, 2010.

Binder Intensity ($kg.m^{-3}.MPa^{-1}$)

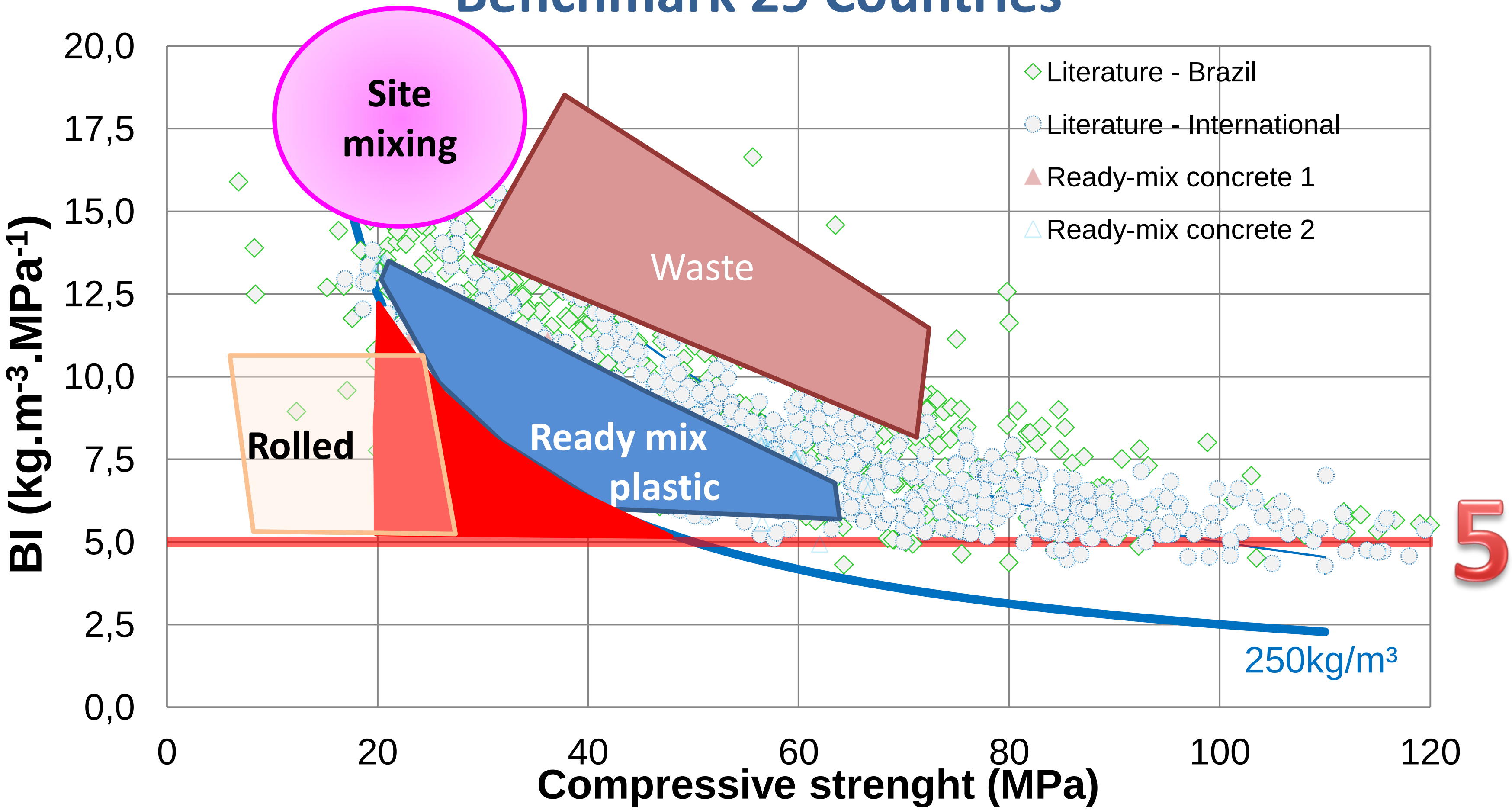
Benchmark 29 Countries



DAMINELI, B. L. KEMEID, F. M. AGUIAR, P. S.; JOHN, VANDERLEY M. Measuring the eco-efficiency of cement use. **Cement and Concrete Composites**, v. 32, n. 8, p. 555-562, 2010.

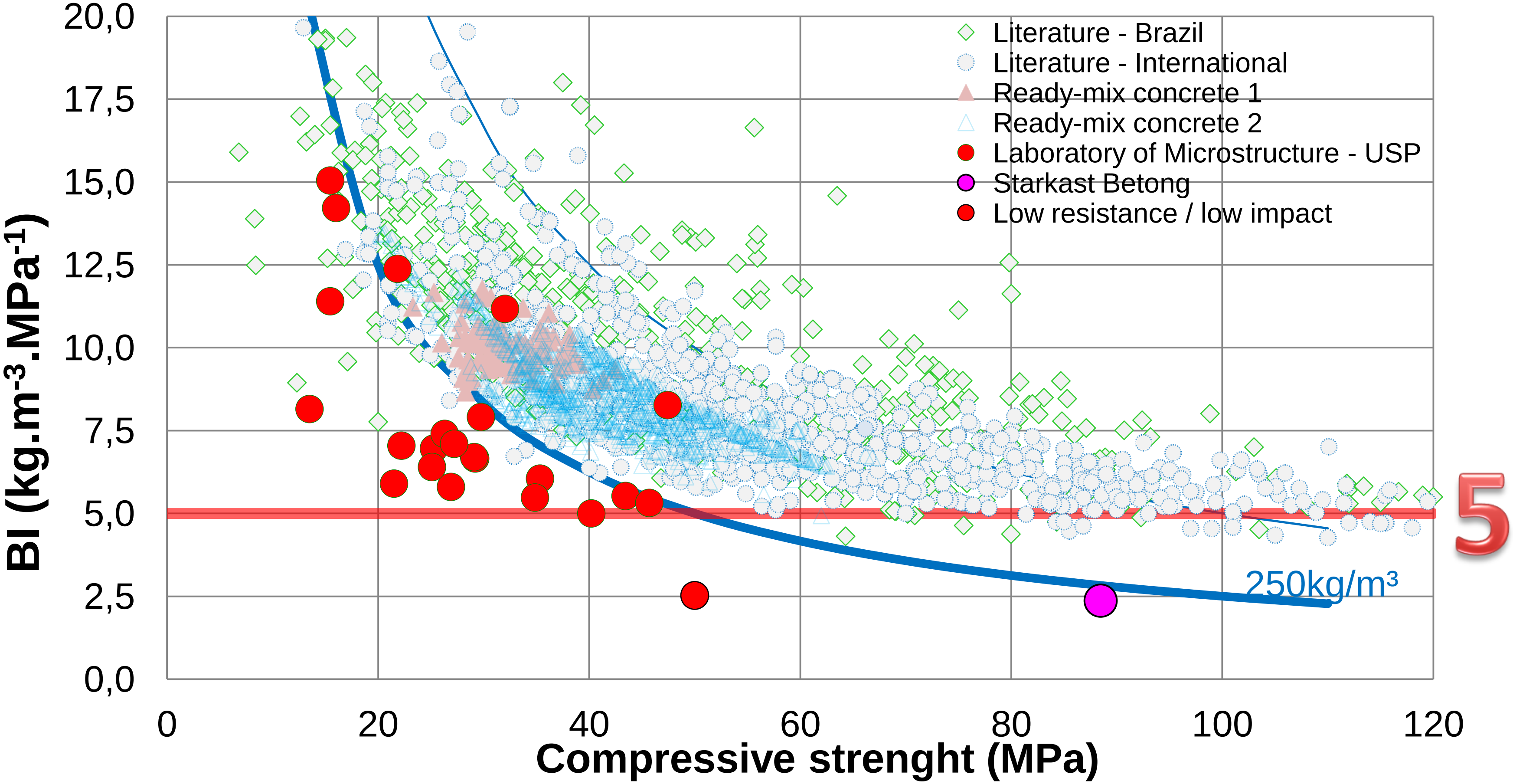
Binder Intensity ($kg.m^{-3}.MPa^{-1}$)

Benchmark 29 Countries



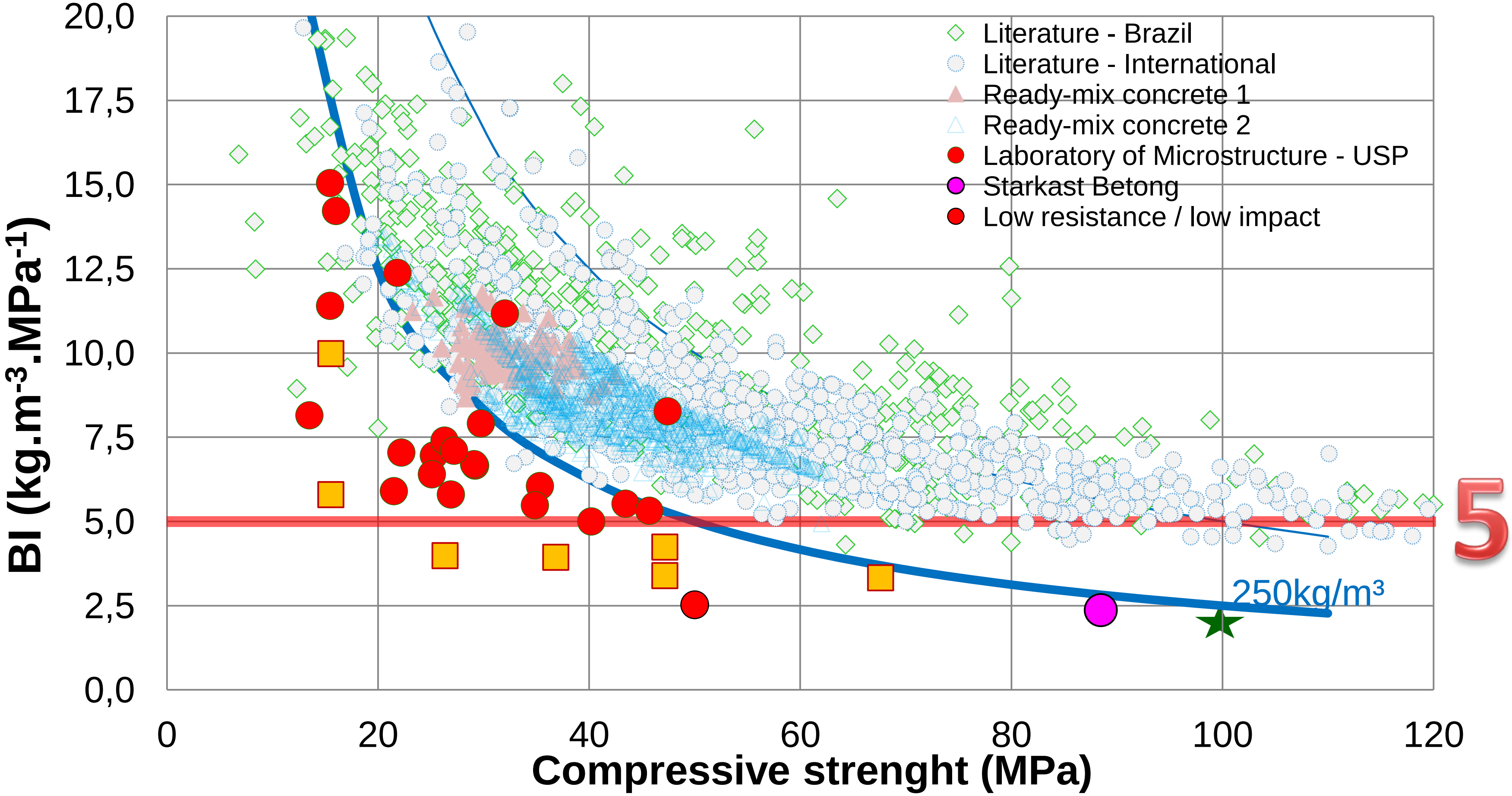
Low BI Concrete Formulation

(USP)



DAMINELI, B. L. - D.Sc. Thesis, 2013 Slump> 150mm

Low BI Concrete Formulation
(USP + Darmstad + KTH/CBI)

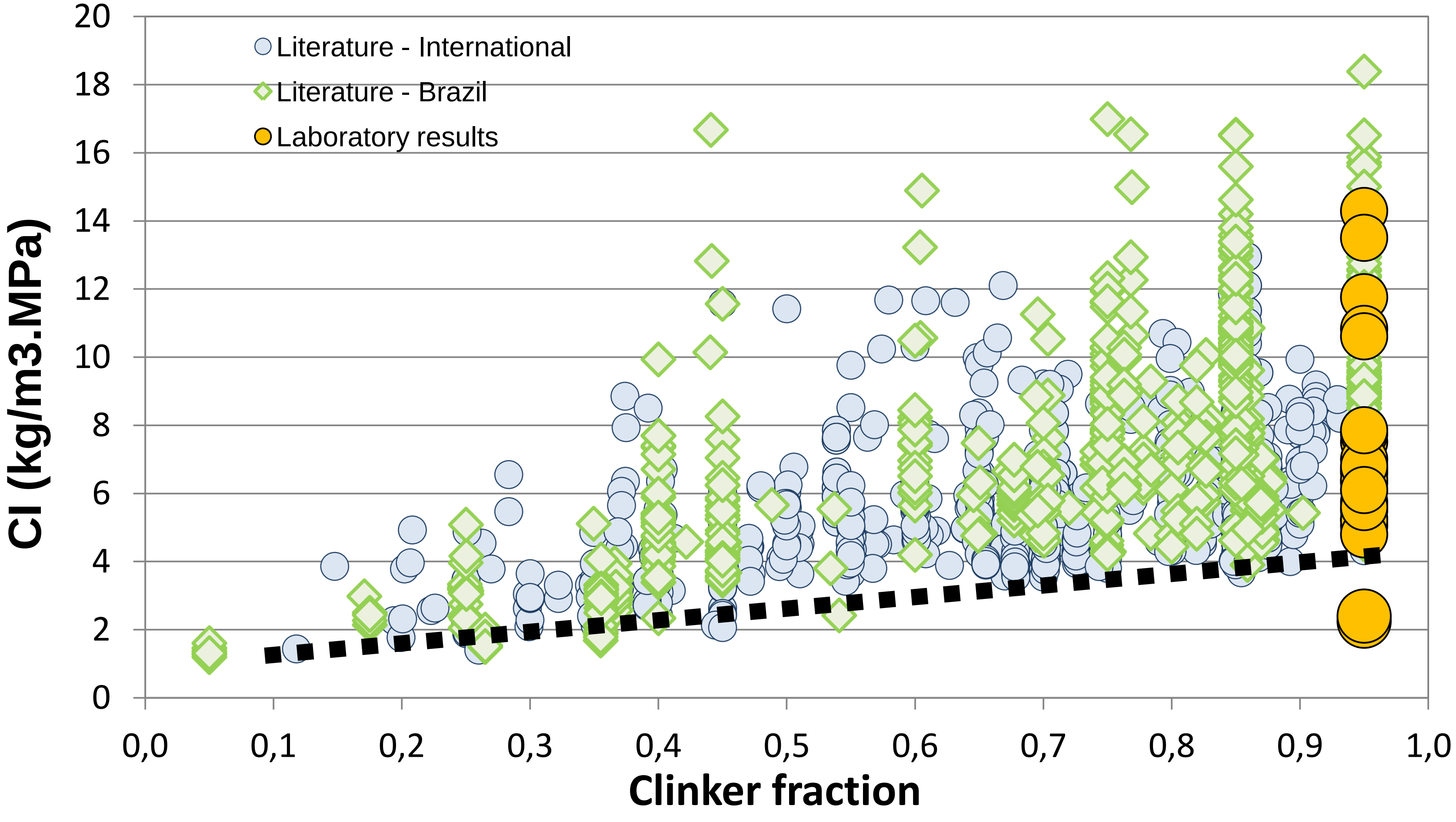


DAMINELI, B. L. - D.Sc. Thesis, 2013. Slump> 150mm

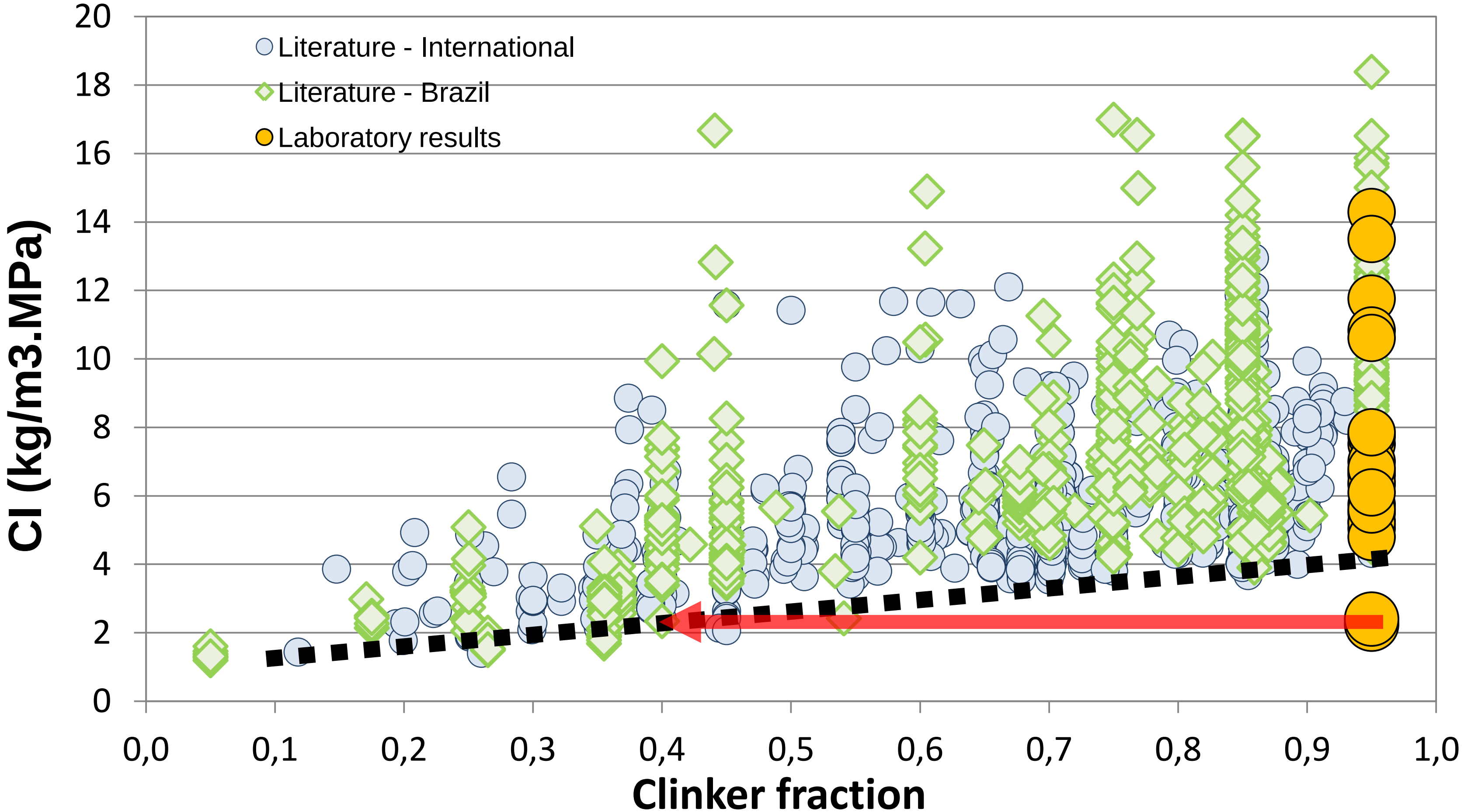
Proske et al. Approach for eco-friendly concretes with reduced water and cement content. ICCS 2013. p288 . Slump> ~55mm

VOGT, C. Ultrafine particles in concrete:. KTH Dr. Eng. Thesis 2010. 155 p

CO_2 Intensity
(USP results)



CO_2 Intensity
(USP results)



T Proske's (TU Darmstadt) Concretes

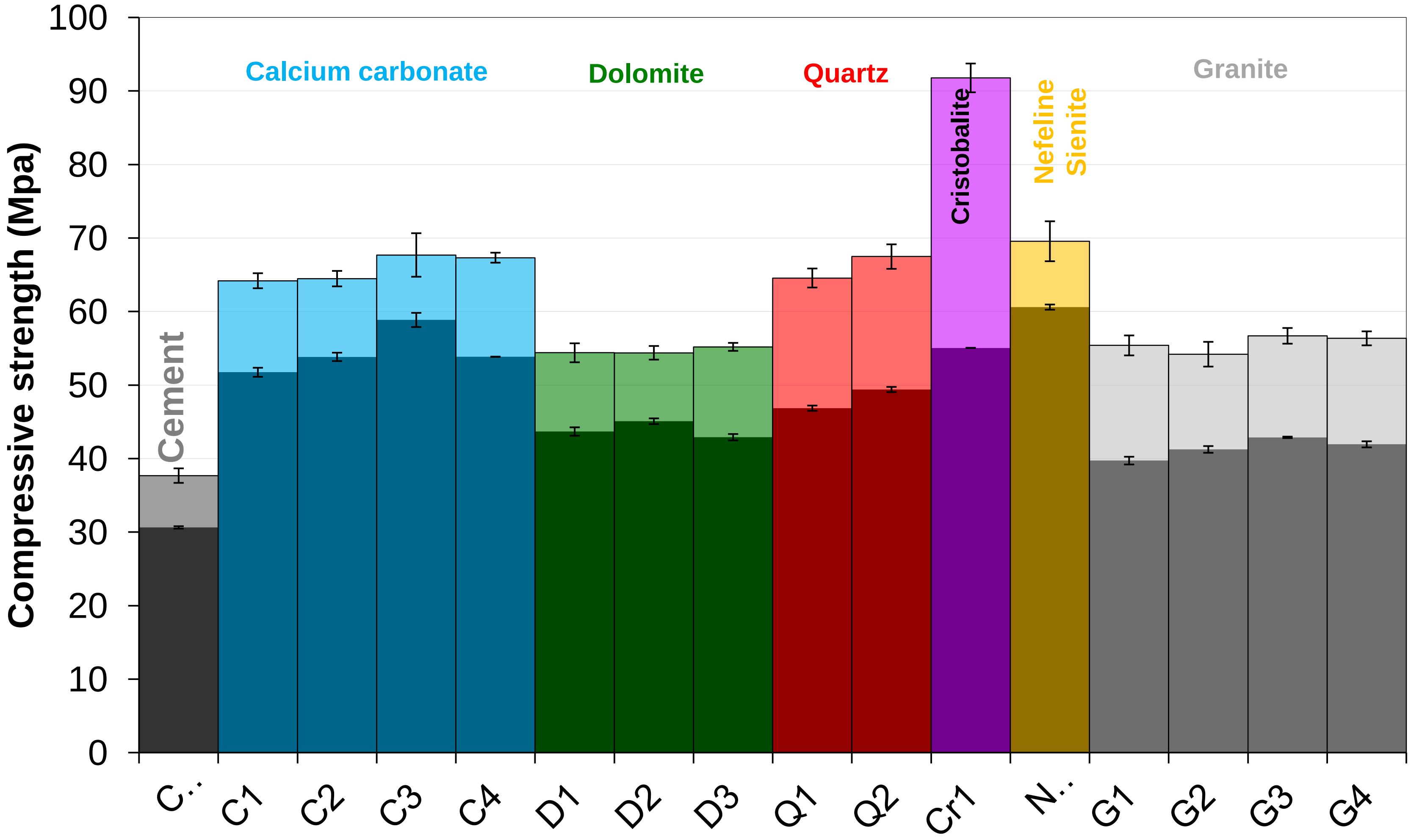
CS (MPa)	Paste kg/m³			w/c	Bi	Reduction (%)
	Binder	Filler	Water			
20 (15,5)	90	270	141	1,57	5,8	59
	220		199	0,90	14,2	
40 (37,8)	145	269	123	0,85	3,9	45
	265		185	0,70	7,2	
70 (67,6)	225	225	114	0,51	3,3	32
	330		164	0,50	4,9	

Proske et al. Approach for eco-friendly concretes with reduced water and cement content. ICCS 2013. p288 .

Slump ~55mm, CEM I 52,5 R, Paste volume 0,270m³/m³

50% Filler Substitution in Cement

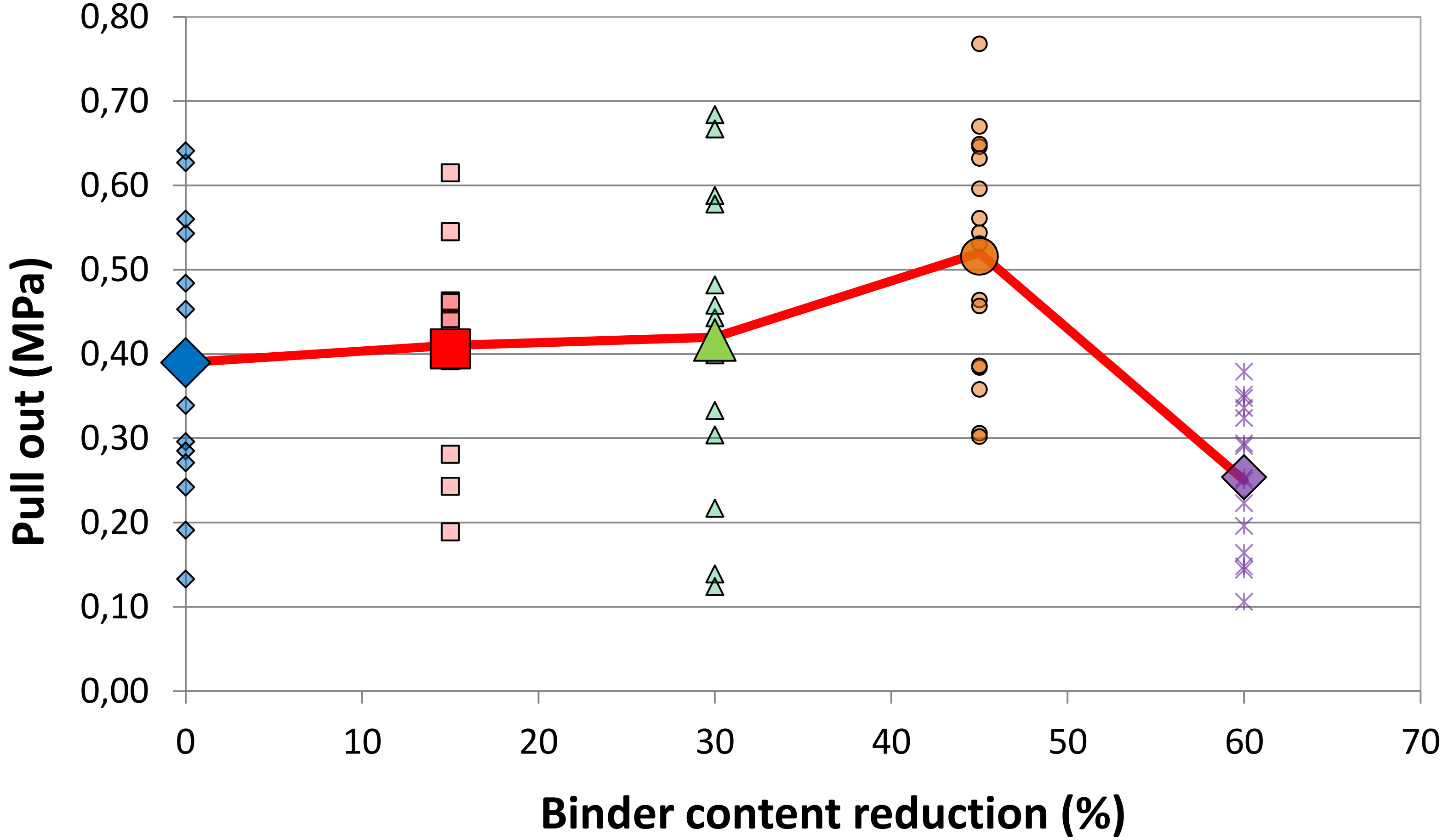
(w/c = 0.5 + optimum dispersant content)



DAMINELI, B. L. - D.Sc. Thesis, 2013. Slump> 150mm

Adhesion in Rendering Mortars

(water/solids 16.5% + dispersant)



Eliane B. C. Costa PhD Thesis 2014 – CONSITRA - Projeto FAPESP

Low Binder Concrete Advantages

- Lowers concrete cost
- Very low CO_2 footprint
- Low hydration heat
- Possible reduction of shrinkage and creep

Low binder concrete difficulties

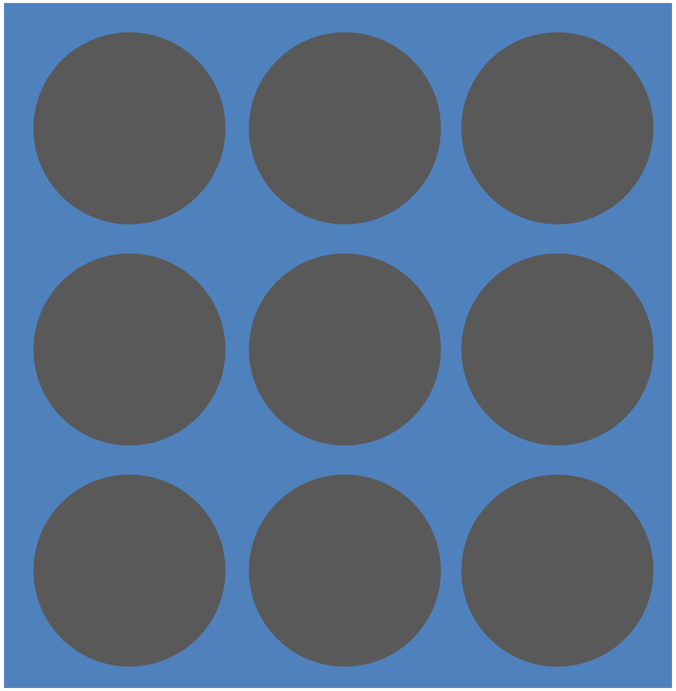
- Water content control (sand humidity)
- Need to combine several materials in a batch
- Compatibility binder – dispersant
- Mixing equipment
- Long-term performance

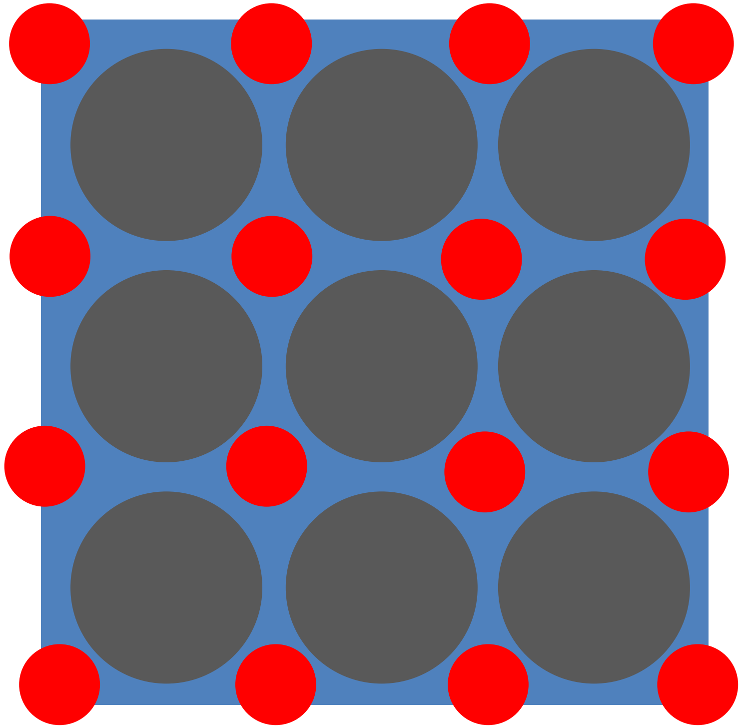
HOW IT IS DONE

Low-Binder Basics

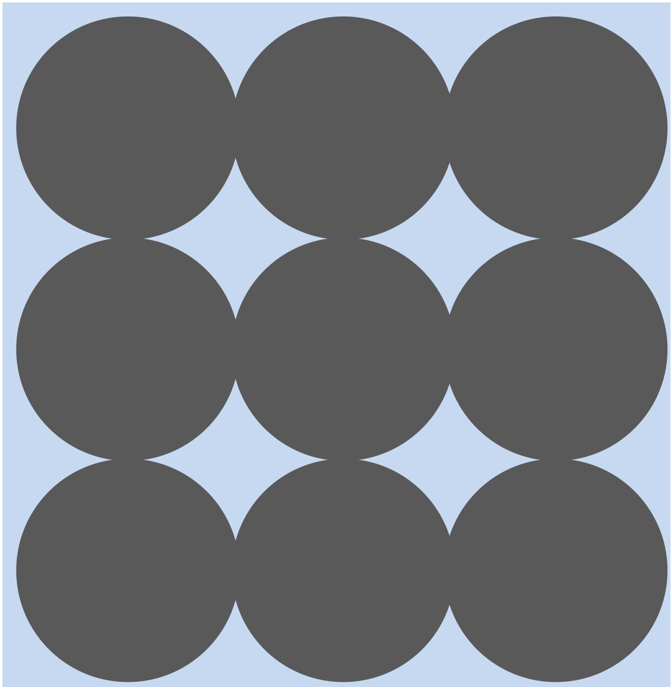
- **Packing aggregates (coarse and sand)**
  lower paste volume (binder, filler, water) needed to fill de voids and give mobility
- **Dispersion of paste particles**
  reduces the amount of water needed to good rheological behavior
- **Packing paste with ultrafine particles**
  reduces amount of water to fill the voids and good rheological behavior
- **Control of rheological behavior**
- **Reactive binder**

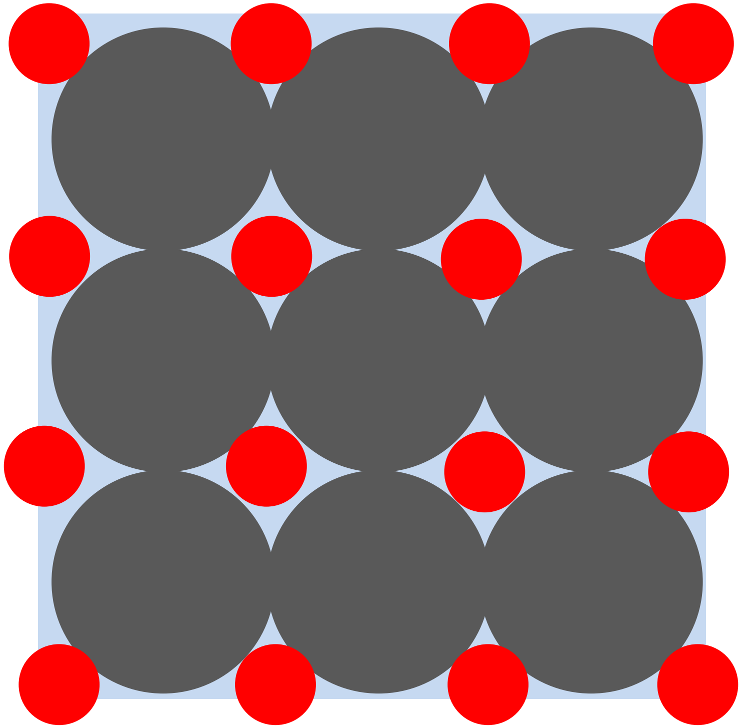
Packing reduces water demand for workability





Packing reduces porosity and increase strength

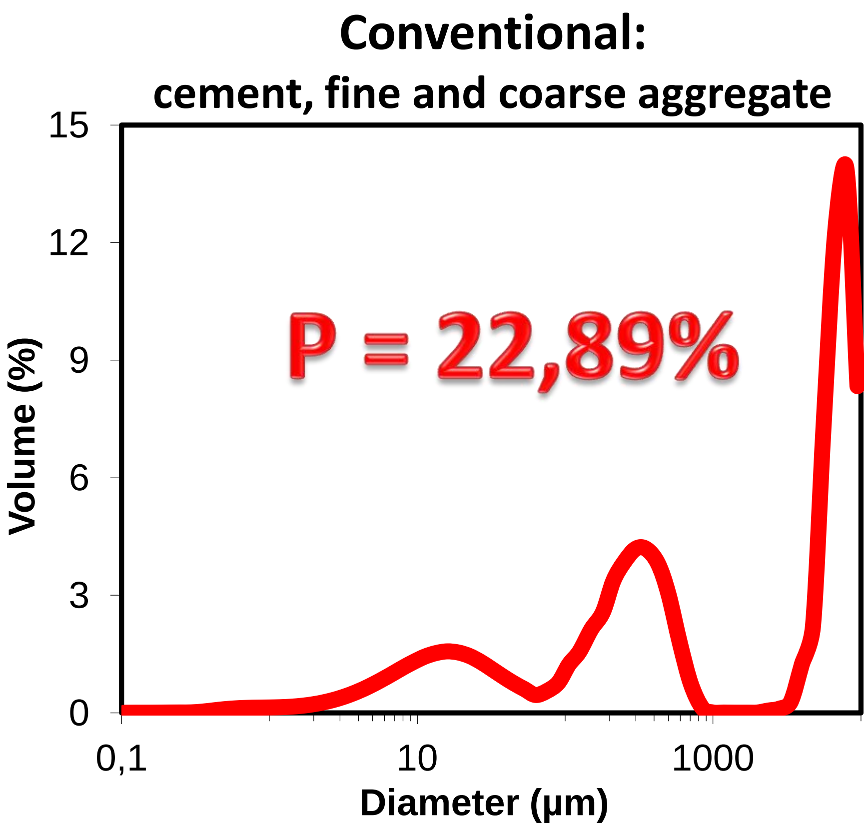


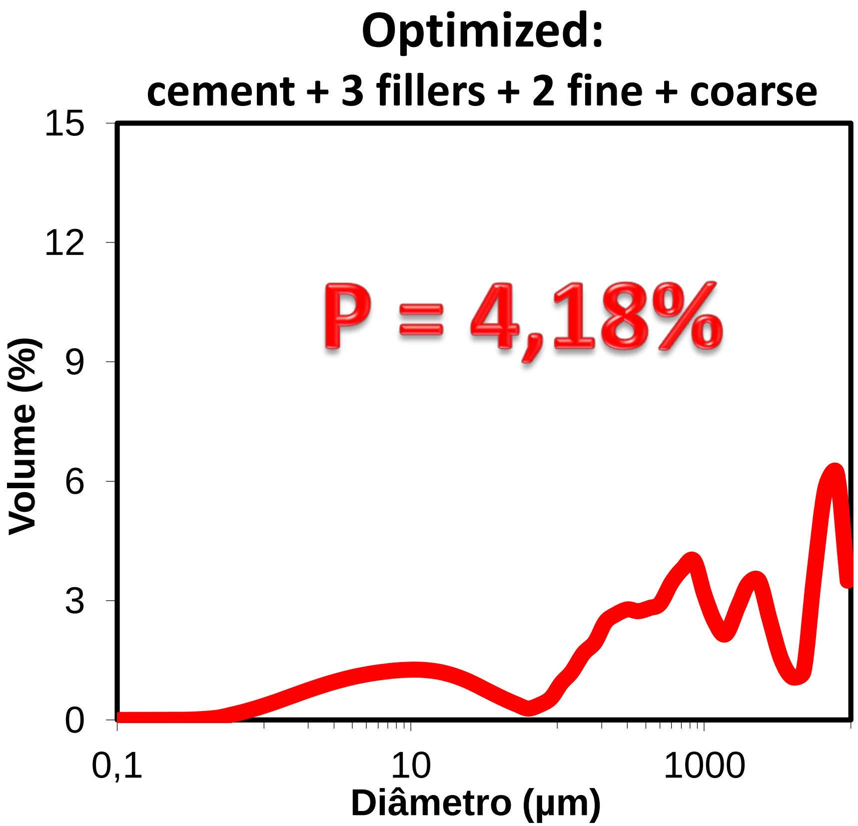


Packing

- **Control of particle size distribution**
  - Air classification
- **Particle shape (image analysis)**
  - Process + raw material
- **Surface area (BET)**
  - Process + raw material
- **Not all fillers are good!**

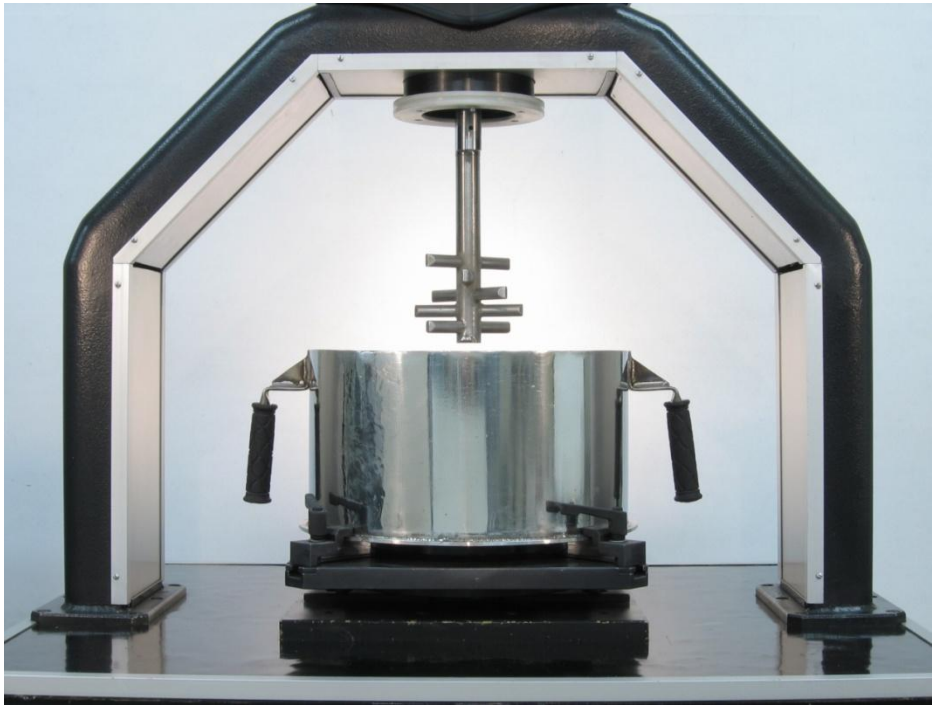
Packing and porosity





Design the rheological behavior of paste and concrete

Paste rheometer



Concrete Planetary mixing rheometer design: Rafael Pileggi (USP)

Binder content and durability

No influence: >180kg/m³

Materials and Structures (2009) 42:973–982
DOI 10.1617/s11527-008-9436-0

ORIGINAL ARTICLE

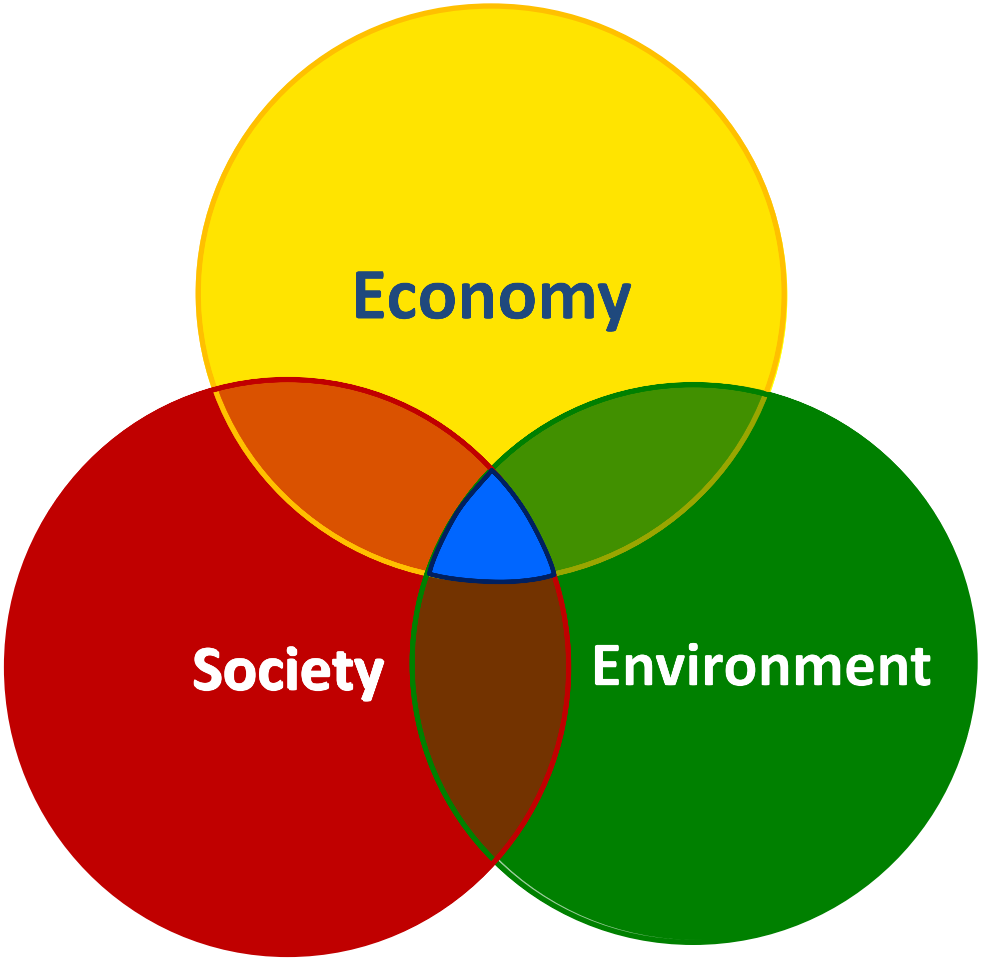
Minimum cement content requirements: a must or a myth?

R. Wassermann · A. Katz · A. Bentur

Binder content and Carbonation

- **Equivalent carbonation depth for binder > 150-170kg/m^3**
- Proske et all. (2013)

Low binder: A Sustainable Solution



Impossible to stop!

Low-binder: two routes

Filler mix on site	Fillers mixed at the cement plant
Reduction cement sales	Cement demand not affected
Feasible for technically capable consumers	Large scale: all consumers included
CO2 reduction for the cement users only	Significant CO_2 emissions reduction for all
Cement production costs will rise	Cement production costs might be reduced

Low-binder: two routes

Filler mix on site	Fillers mixed at the cement plant
Reduction cement sales	Cement demand not affected
Feasible for technically capable consumers	Large scale: all consumers included
CO2 reduction for the cement users only	Significant CO_2 emissions reduction for all
Cement production costs will rise	Cement production costs might be reduced
	sustainable solution

Low-binder cement: the good

- **Calcination replaced by grinding and separation**
- **Reduction of thermal energy**
- **Increase yield from limestone quarry**
  - CO_2 is part of the product (44%)
  - Use of “low-quality” limestone
  - Other sources of filler can be explored

Low-binder cement: the good

- CO_2 mitigation without increasing costs
- Might reduces the capital cost
- Preserve industry's investment

Low-binder cement: the tricky

- **Requires developing new knowledge**
- **Need better control of water in concrete**
  - Dry sand?
  - Better "on line" sensors
- **Increase electricity consumption**
- **Dispersants will become a raw material**
- **In mature markets it might imply in a increase of production capacity**

Conclusion

- **Low-Binder concrete will succeed in the market**
  - Low cost
  - Low environmental impact (CO_2, Energy)
  - Socially responsible
- **Who is going to capture the value?**
  - Cement industry?
  - Filler producers?

Conclusion

- **Vision: Reduce 50% the binder content by**
  - Engineered fillers
  - Better aggregates
  - Dispersant in cement bags

Sources

- DAMINELI, B. L. KEMEID, F. M. AGUIAR, P. S.; JOHN, V. M. Measuring the eco-efficiency of cement use. Cement and Concrete Composites, v. 32, n. 8, p. 555-562, 2010 (DOI:10.1016/j.cemconcomp.2010.07.009)

- Damineli, Pileggi, John Low binder eco-efficient concretes. In: Pacheco- Torgal, Jalali, Labrincha e John, Eco-efficient concrete. Woodhead 2012.

Muito obrigado pela atenção!