Low CO_2 alkali activated ash binders

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Building Technology Group
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BRE, Garston, Watford

Low CO_2 alkali activated ash binders

- Low CO_2 binders- the global context
- Introducing alkaline activated ash (AAA) binders
- How do AAA binders differ from Portland cements ?
- How AAA binders set
- Making concretes using alkaline ash binders
- Properties and durability of AAA binder concretes
- Industrial trials and industrial experience
- CO_2 emissions/environmental impacts
- Future developments

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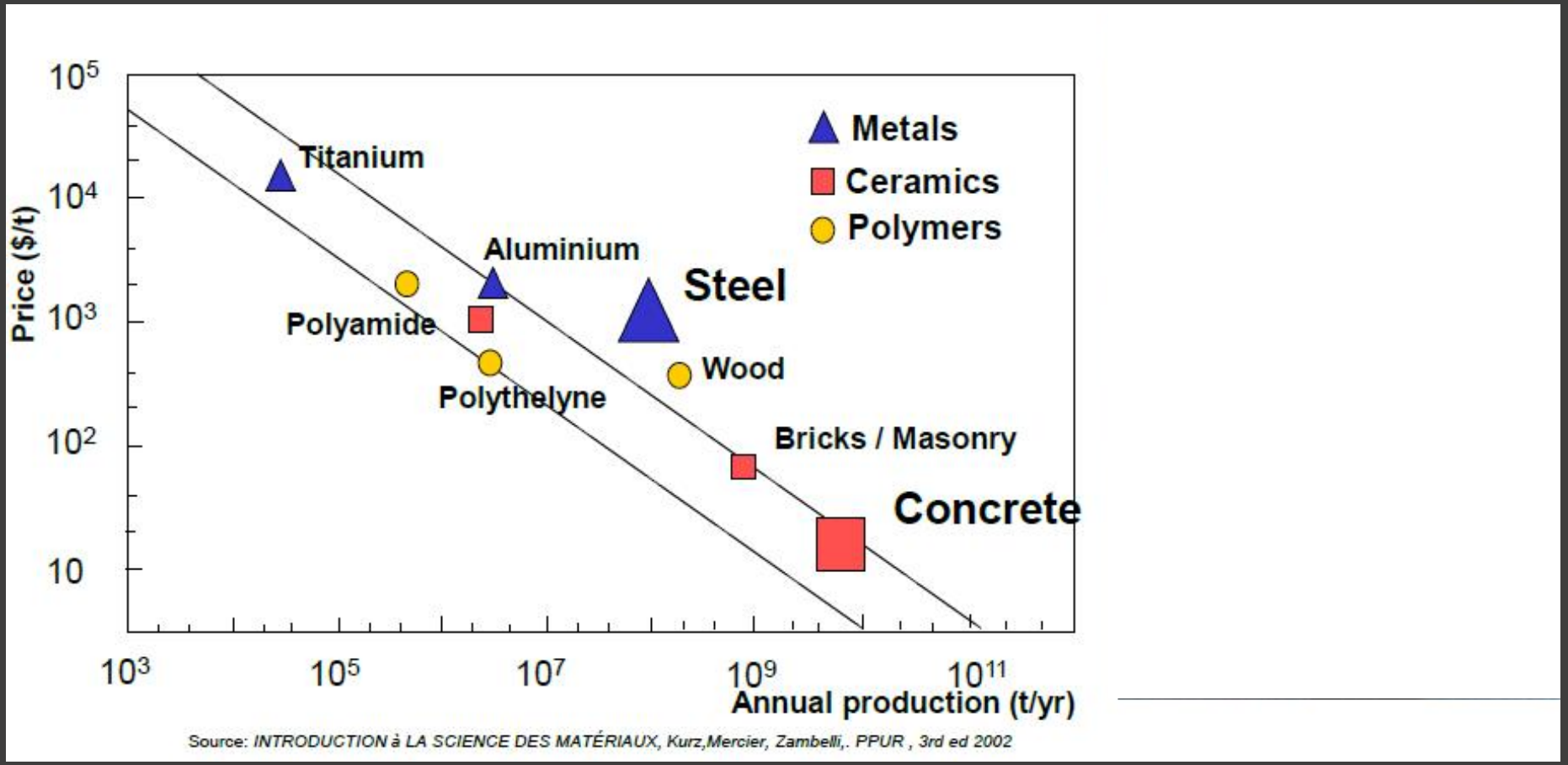
Concrete - the most extensively used construction material in the world



Source: *INTRODUCTION à LA SCIENCE DES MATÉRIAUX, Kurz,Mercier, Zambelli,. PPUR , 3rd ed 2002*

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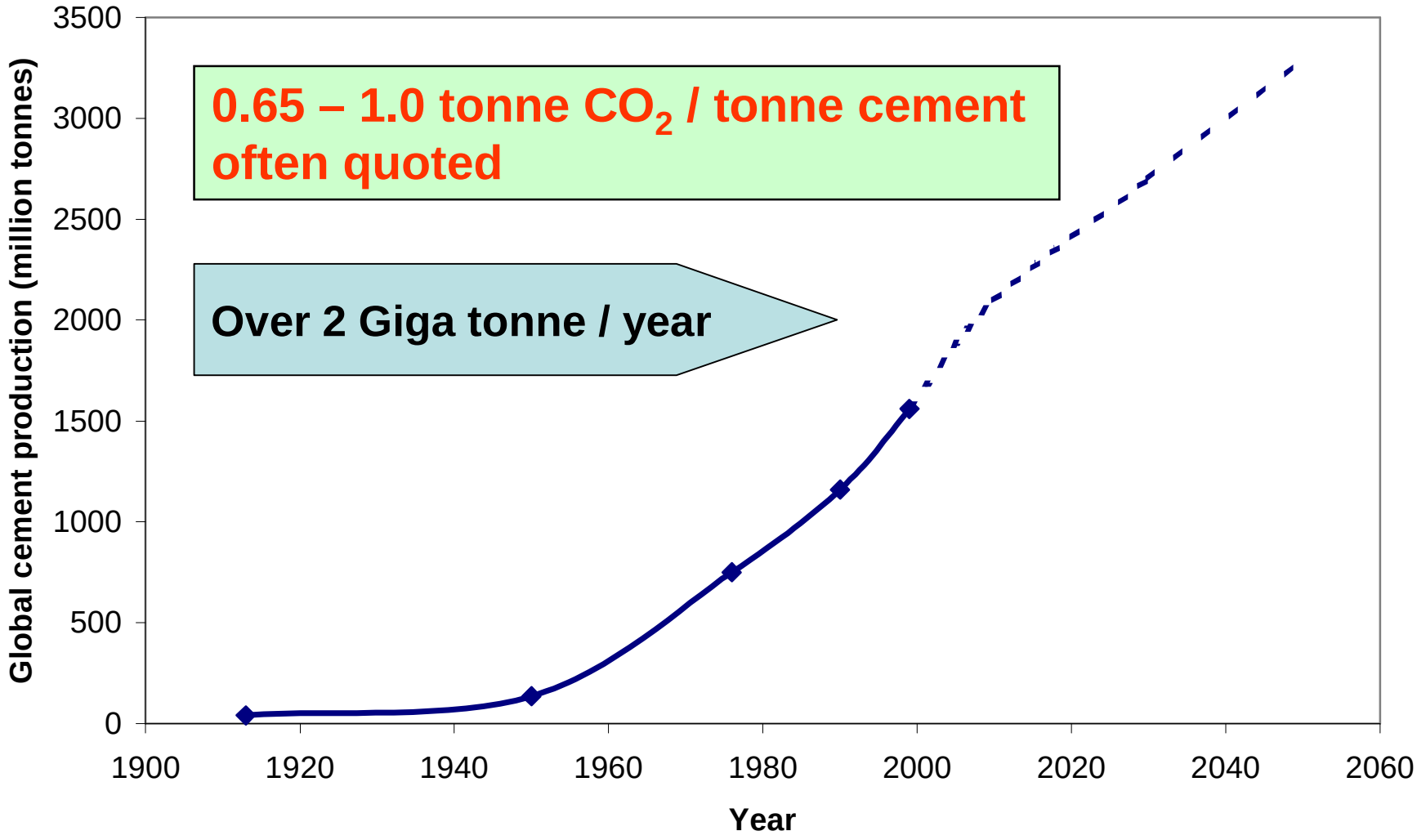
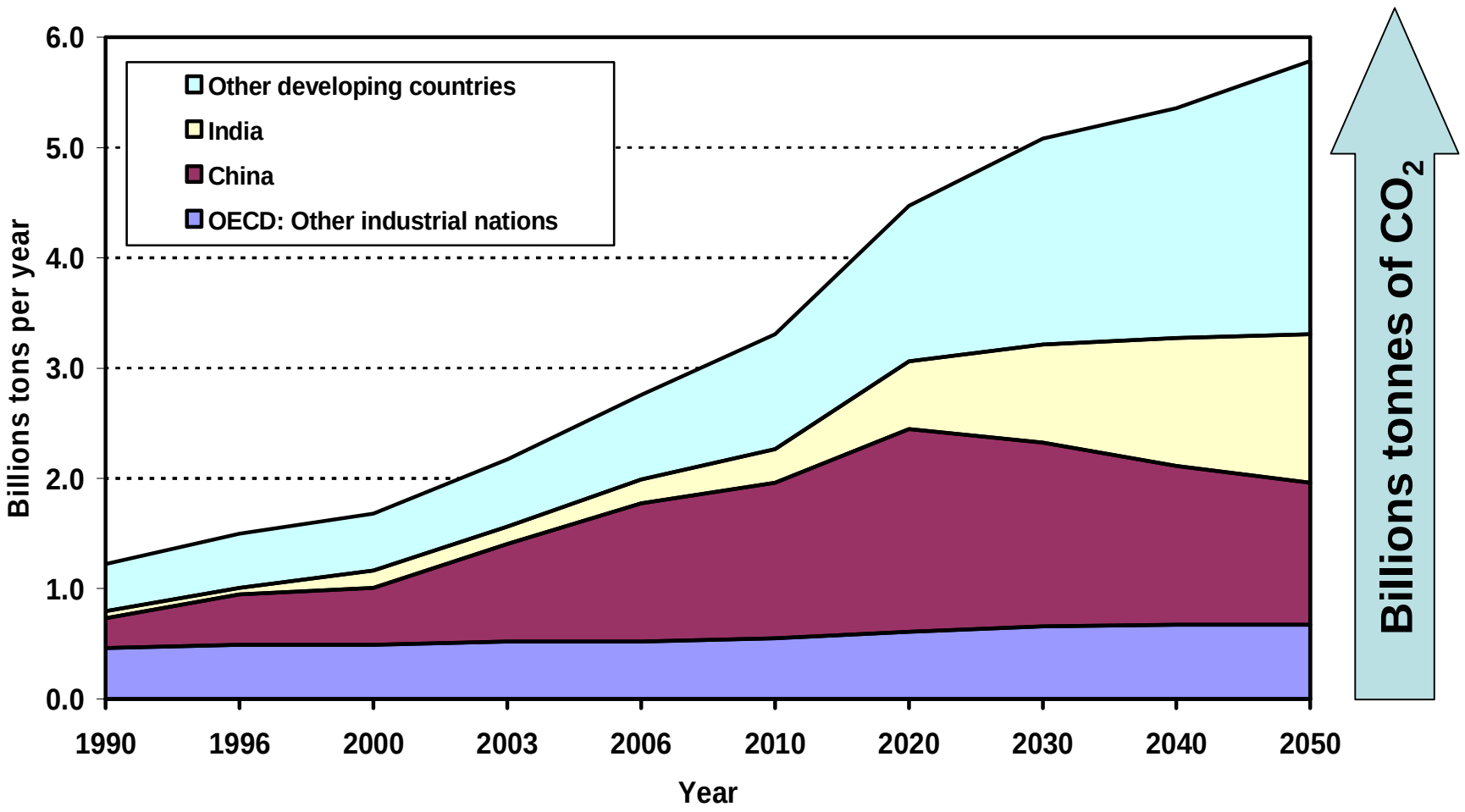
Global cement production





Source: K Scrivener, *Future Cementitious Materials and Durability*, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China

Activated binder concrete

Alkali activated binders are a novel type of cement system with a significant benefits relative to Portland cements including:

- Binders produced from readily available waste / by-product materials such as power station and related ashes
- High early strength
- Potentially enhanced durability (particularly good chemical resistance and resistance to high temperatures)

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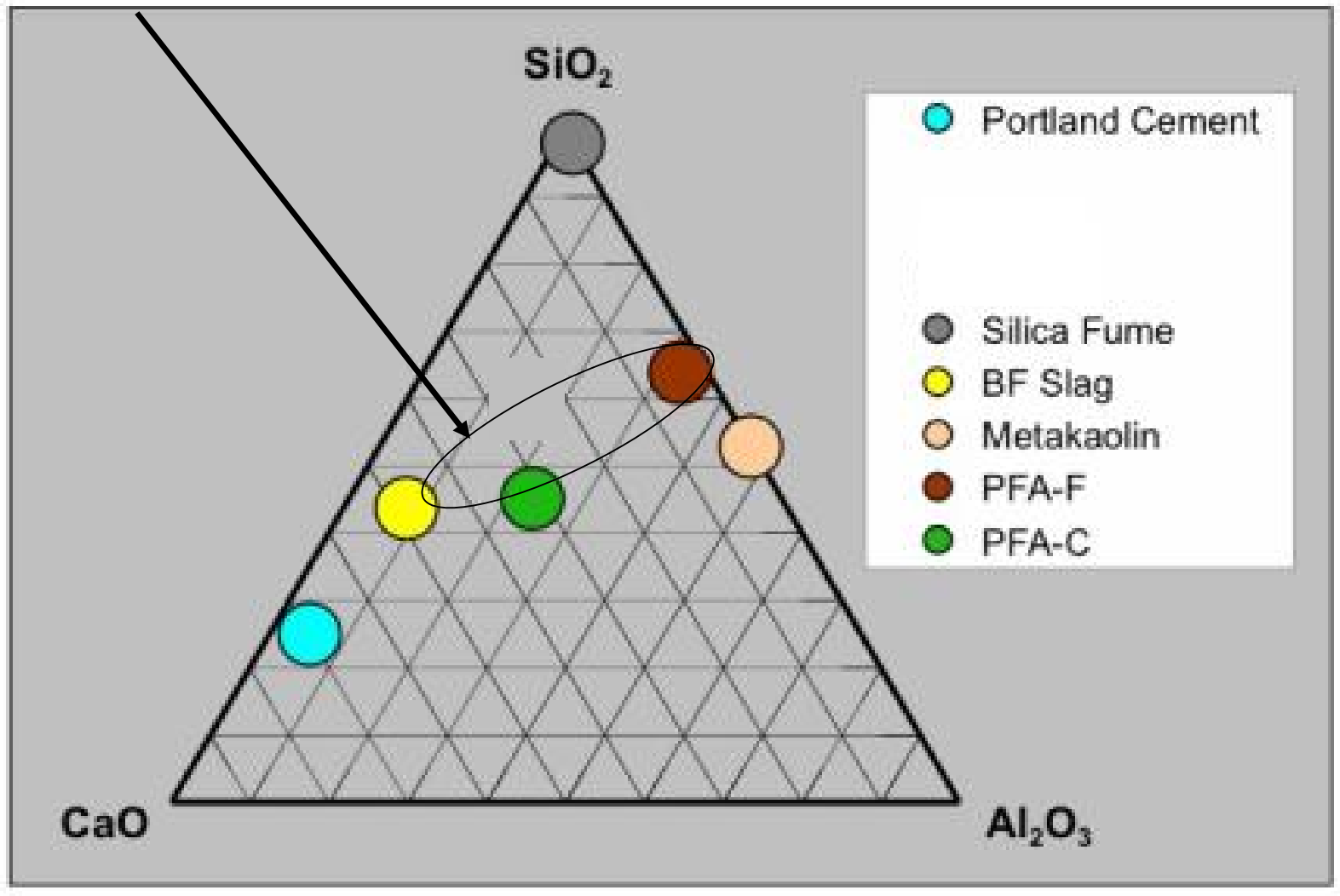
BRE studies



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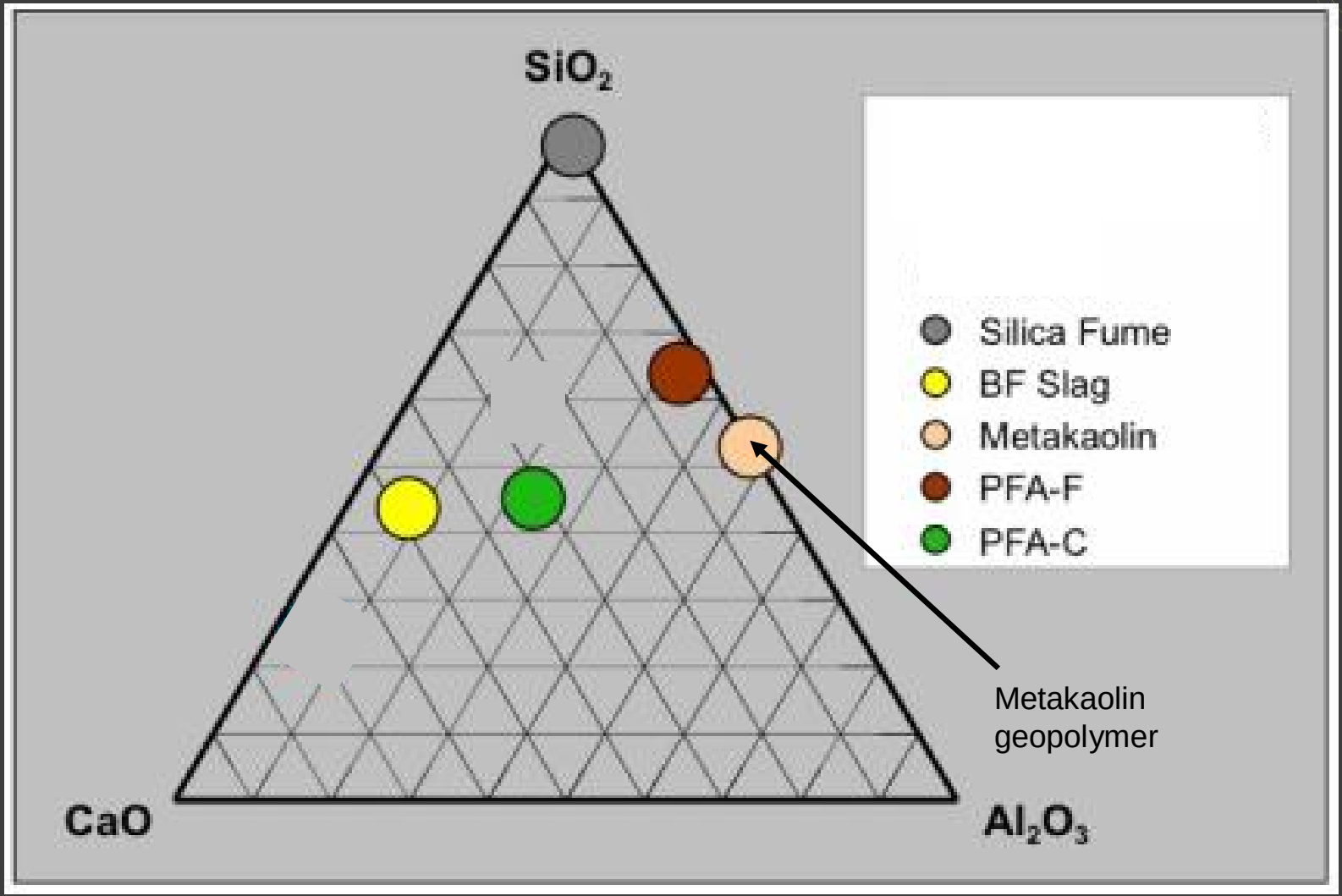
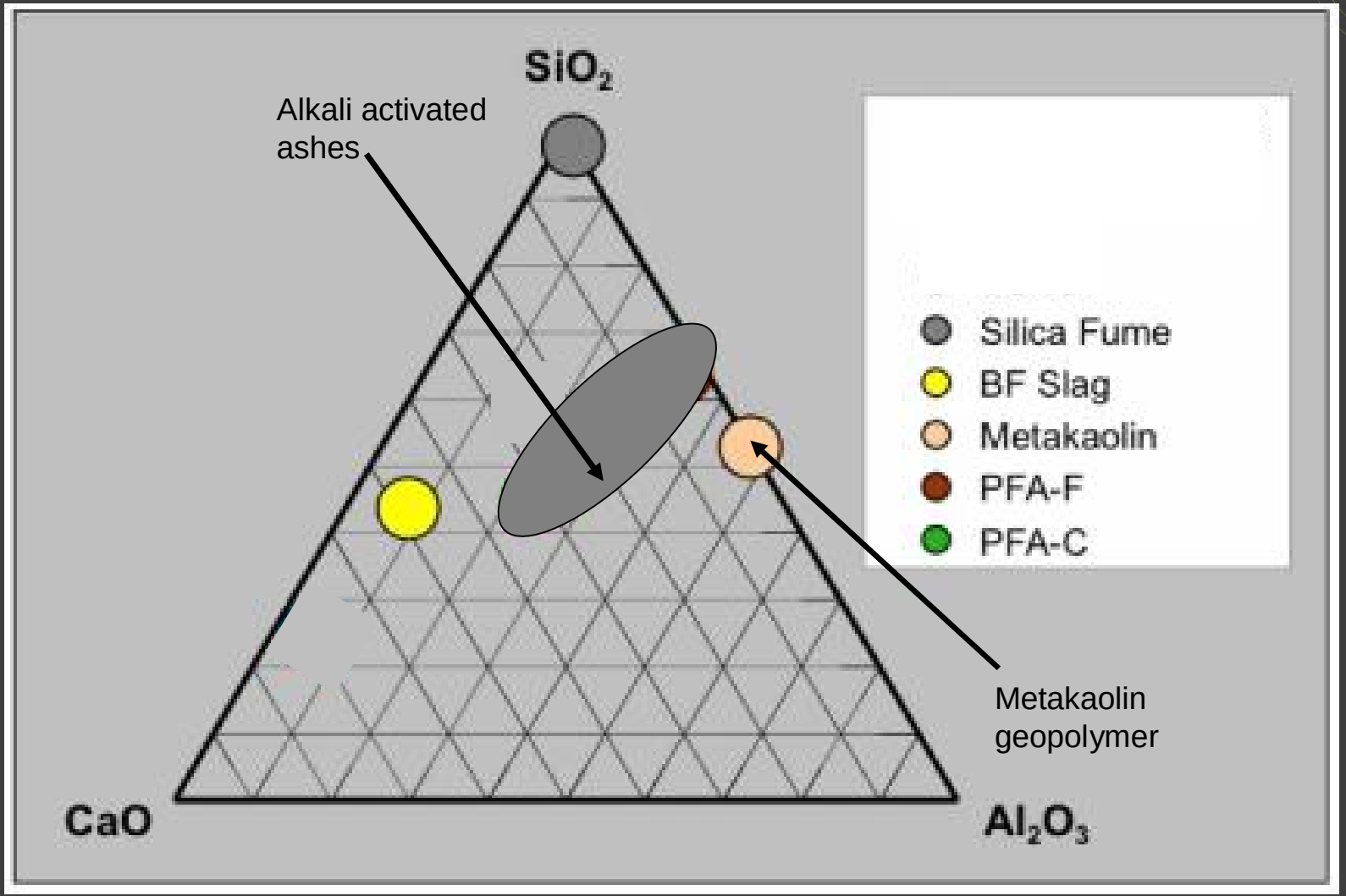
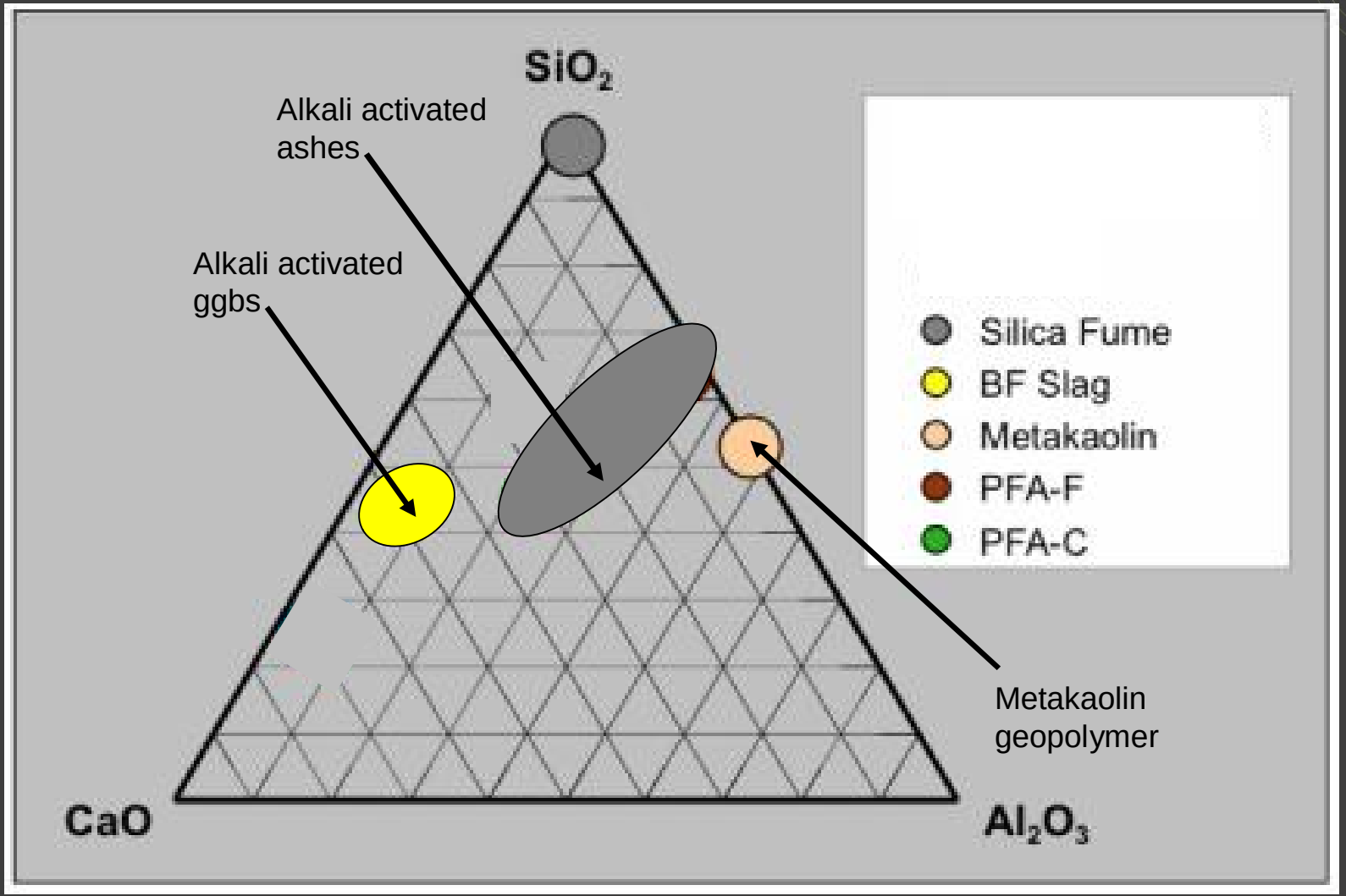
Alkali activated systems



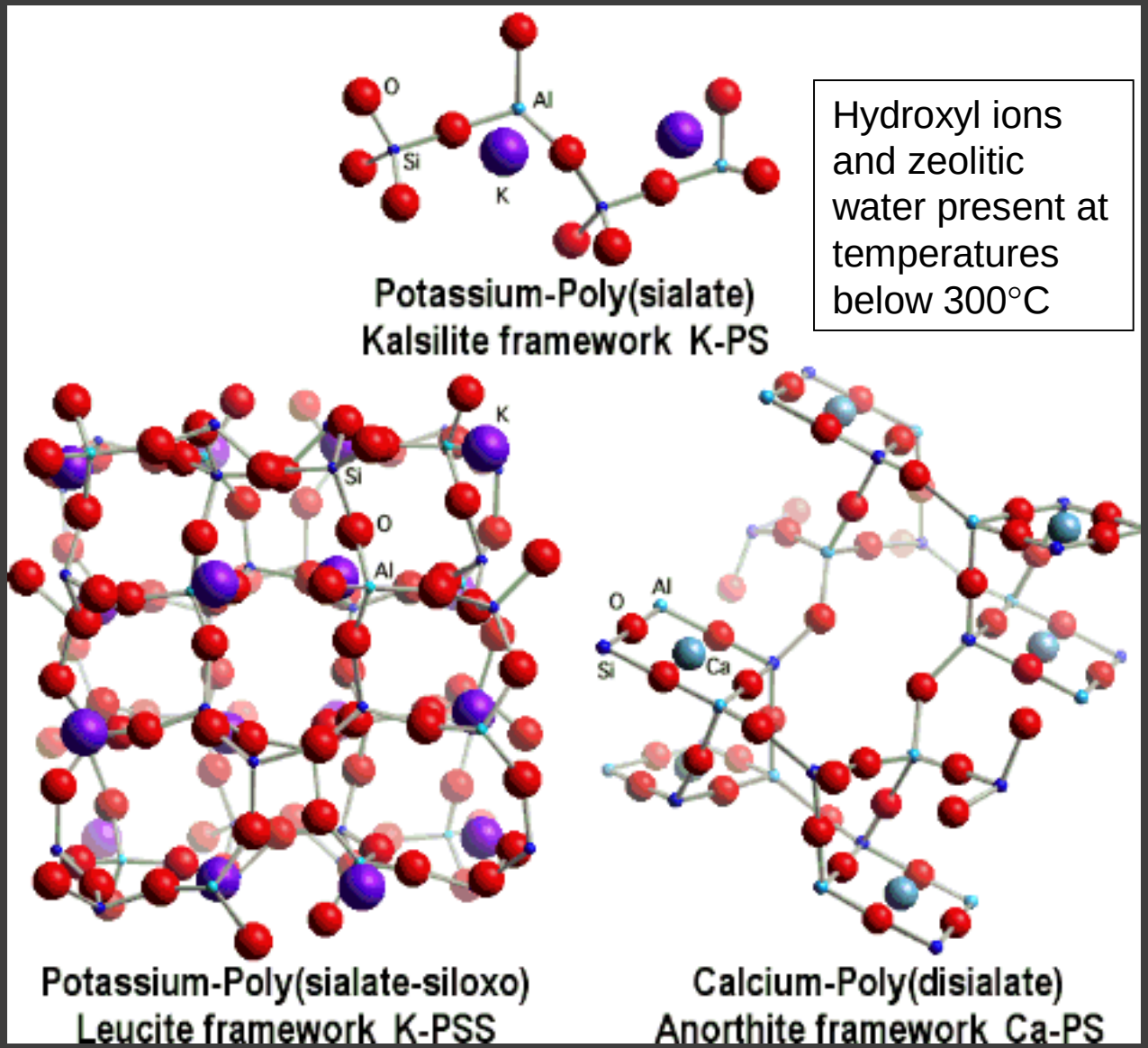
Alkali activated systems



Alkali activated systems



Geopolymer Frameworks



(after the Geopolymer Institute)

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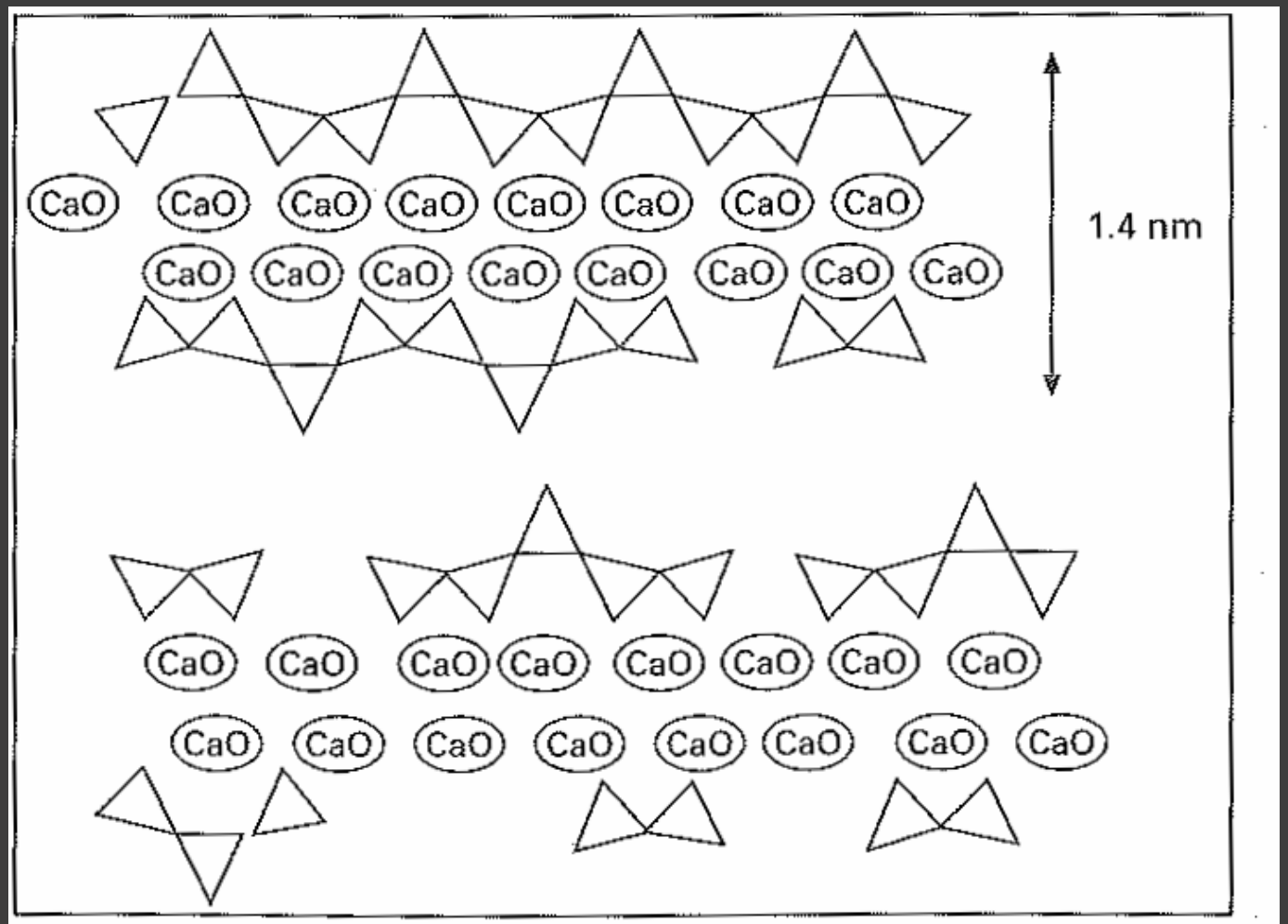
C-S-H gel structure in Portland cement



6.1 Structural model proposed for C-S-H gel (after Taylor 1990)

Reactive solid components known to have been used in alkaline activated binder concretes

Major binder components **(generally alumino-silicates)**	**Minor binder components** **(generally a calcareous component)**
– Class F fly ash (or pfa) – Class C fly ash (or pfa) – Ggbs – Calcined clays – Unfired clays – Colliery wastes – Mining wastes	– Ggbs (from iron manufacture) – Portland cement (PC)

Locally available raw materials with minimal processing required

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Setting and hardening

- Dissolution of the glassy alumino-silicate component of the binder due to high pH conditions
- Chemical interactions with the activators (eg sodium silicates) in solution and consumption of the activator
- Inorganic polymer networks form from solution

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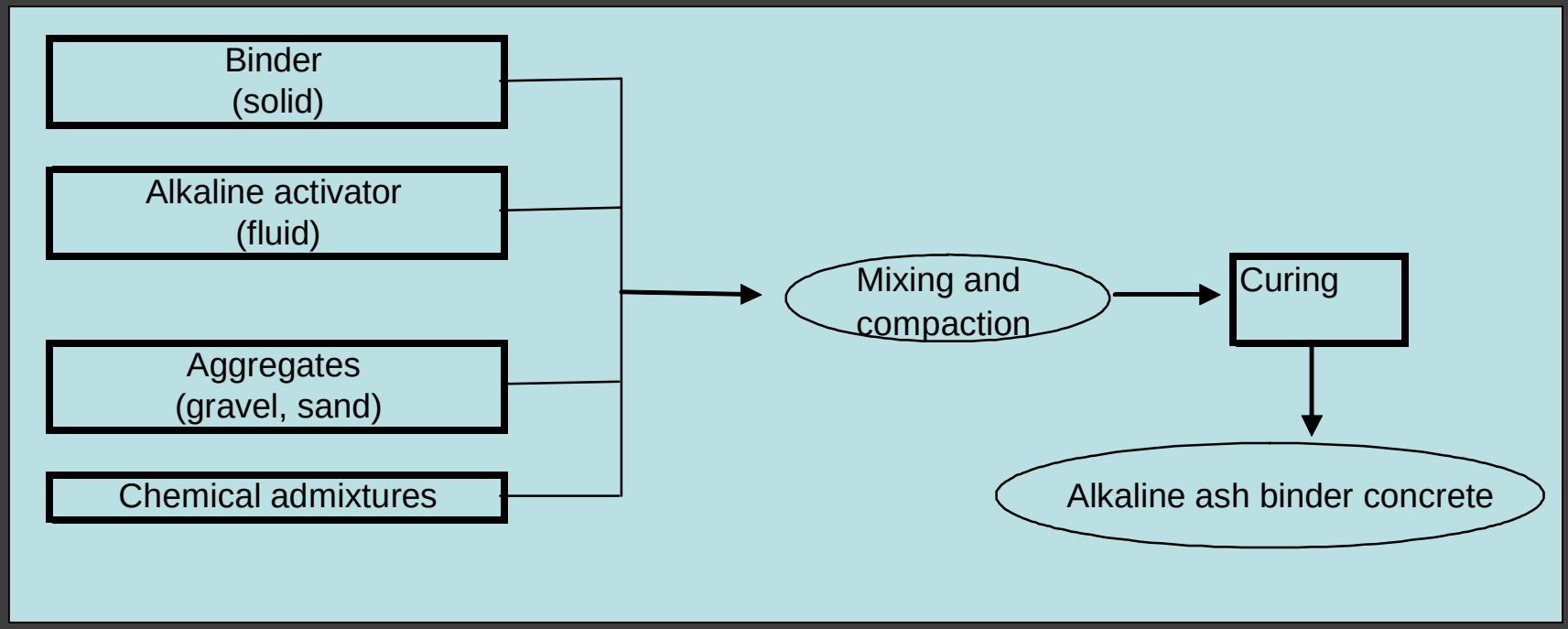
Role of water

- Water does not become part of the molecular network structure and is expelled during curing and consequent drying. It facilitates workability (and provides a solvent for the chemical reactions to occur).

Production of alkaline ash binder concrete



Activated binder concrete products

UK collaborative BRE-led research projects aim to:

- Produce and test alkali activated binder concretes
- Carry out manufacturing trials to identify suitable compositions
- Produce trial concrete products
- Generate performance data on products to facilitate commercialisation

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CARBON TRUST
Making business sense of climate change
CRH
BASF
RB
Marshalls
MARKS & SPENCER
Technology Strategy Board
Driving Innovation
PQ Corporation

BRE role

- Not just science…….
- Barriers to commercialisation
- Focus on materials available in the UK

INFORMATION PAPER IP 9/10

ALKALINE ASH BINDERS

Reduced environmental impacts for precast concrete products

Andrew Dunster, Kofi Abora and Keith Quillin

The production of alkaline ash binders uses less energy and emits less carbon dioxide than that of conventional Portland cement (PC). Alkaline ash binders could also play a major role in reducing other environmental impacts by utilising locally available waste materials and industrial by-products. A recent BRE-led research programme has shown that these binders have the potential to be used on a commercial scale to produce durable concrete products with physical properties comparable to those of equivalent PC concrete. This Information Paper examines the current drive towards reducing the environmental impact of cements through developing alkaline ash binders and presents the results of industrial-scale production trials conducted by two major manufacturers.

Mock-up image of a patio made from Marshalls paving flags
Courtesy of Marshalls

Mock-up image of a roof made from Hardrow® roofing slates
Courtesy of Forticrete

CEMENT AND CONCRETE IN A GLOBAL CONTEXT

Concrete is likely to continue to be the primary volume construction material for most structural applications and its use is likely to grow. Portland cement (PC) and PC blended with pulverised fuel ash (PFA) or ground granulated blastfurnace slag (GGBS) are currently the only economic cement binders for concrete that have been shown to meet the performance and durability requirements under the wide range of conditions to which concrete is exposed.

The demand for cement globally is currently about two billion tonnes per annum. It is forecast (based on the highest demand scenario) to rise to nearly four and a half billion tonnes per annum by 2050 (Figure 1). Total carbon dioxide (CO_2) emissions associated with cement manufacture depend on cement composition, the nature of the raw materials used and the efficiency of the manufacturing process. In modern best practice

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Question of durability

- BRE laboratory-cast concretes for the following long term durability tests:
  - *compressive strength development*
  - *freeze/thaw*
  - *dimensional stability*
  - *sulfates,*
  - *Acid resistance*
  - *Drying shrinkage*

Protection of reinforcement

- Key questions for AA concretes are:
  - *Carbonation: What is rate of CO_2 ingress ?*
  - *Carbonation: Does steel corrode in “carbonated” concretes ?*
  - *Chlorides: What is rate of chloride ingress ?*
  - *Chlorides: What is chloride threshold for corrosion to occur ?*

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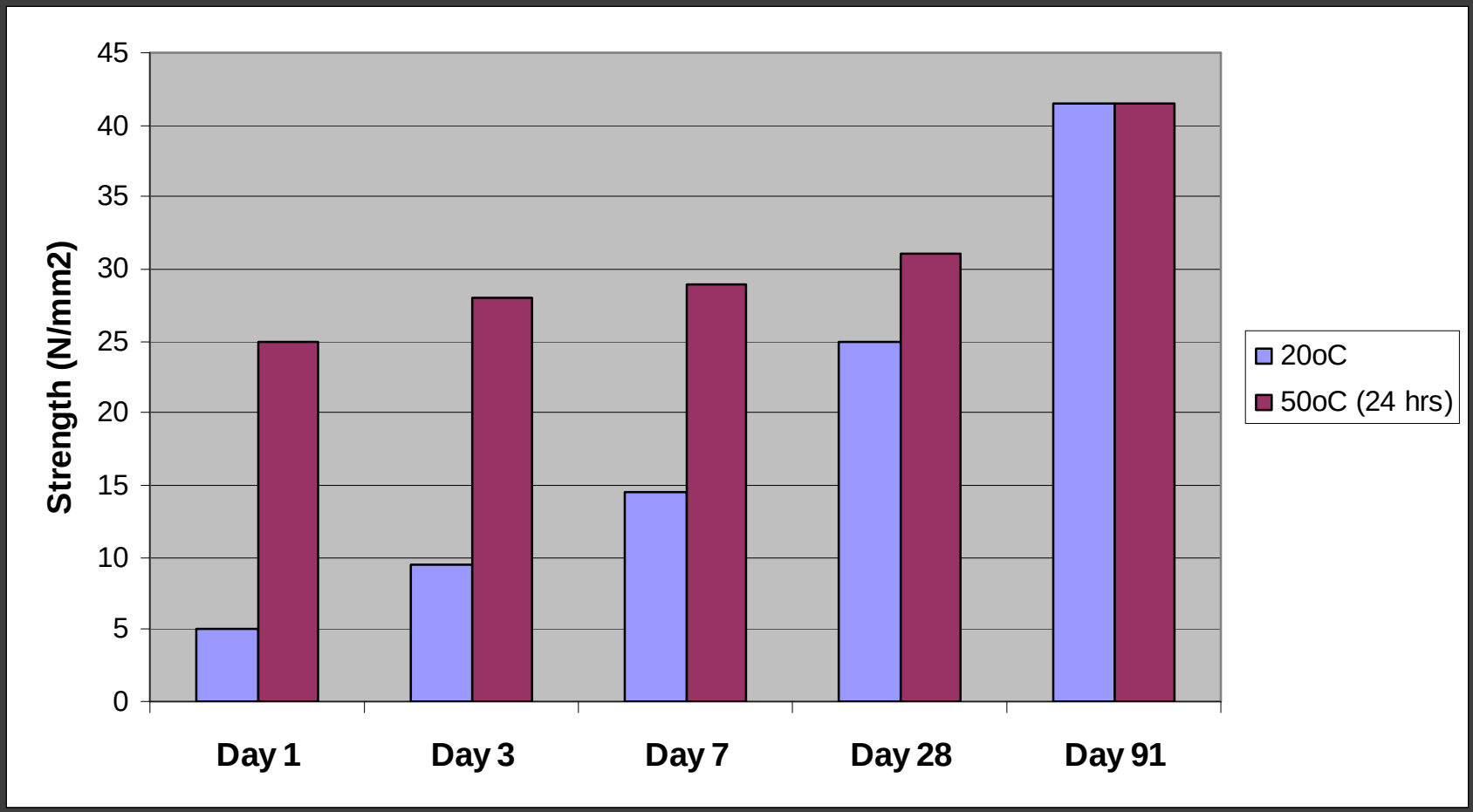
Effects of temperature on strength development



K Abora, BRE

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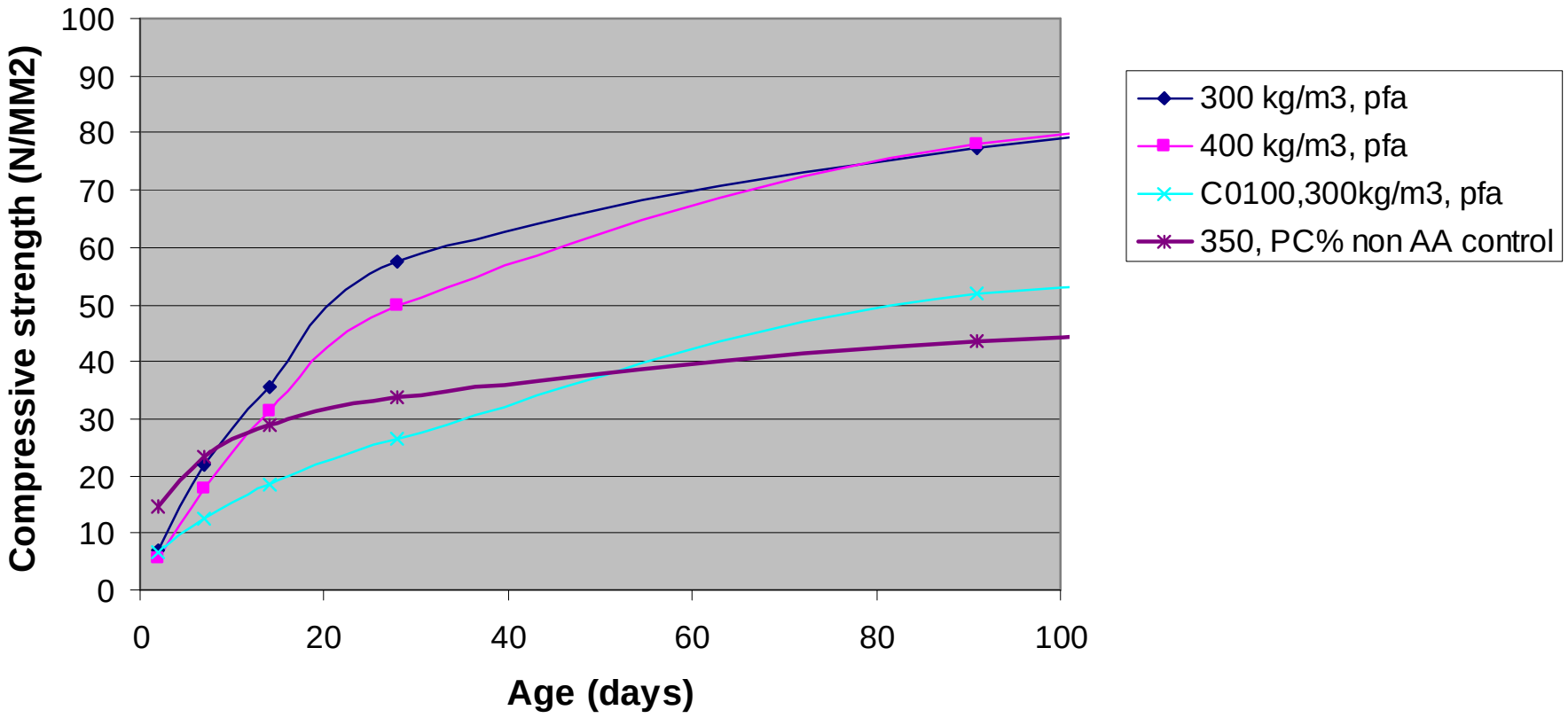
Strength development of ash binder concretes compared with a PC concrete (seal cured)



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PC/pfa control: 182 days in citric acid solution

Alkaline ash binder concrete: 182 days in citric acid solution

PC/pfa control: 15 months in Class 4a sulfate solution

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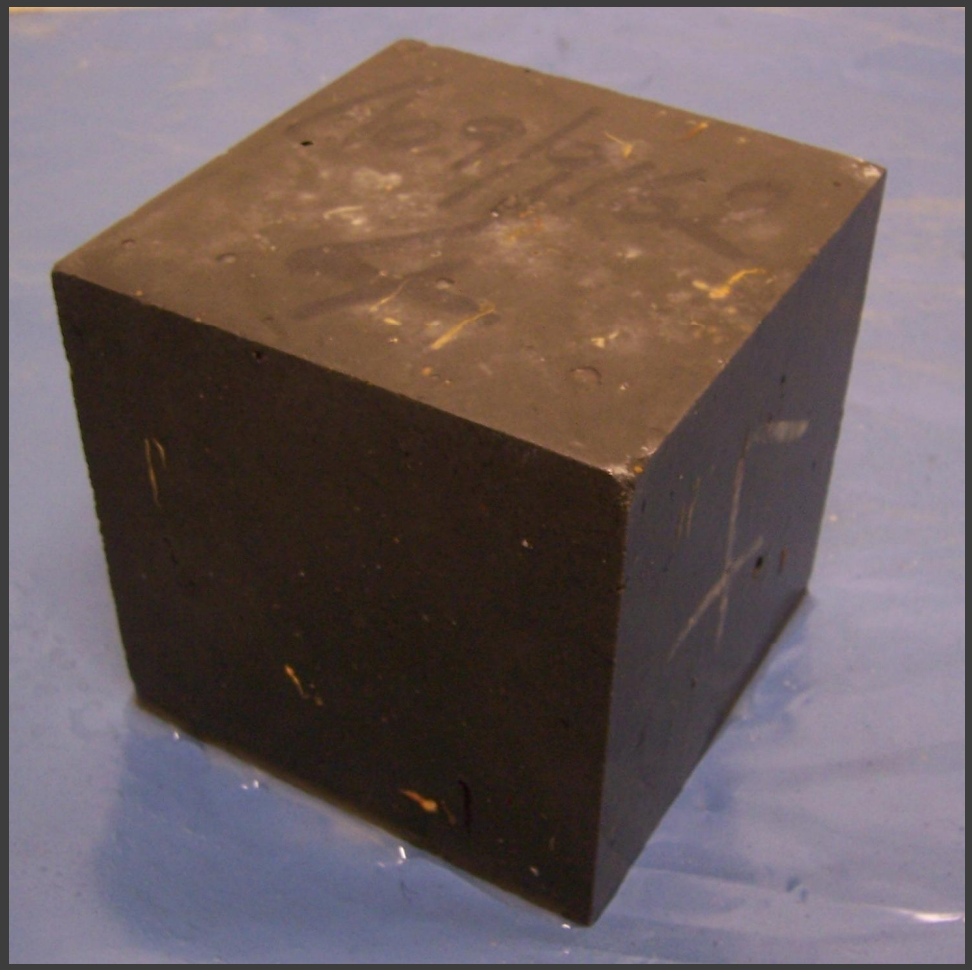
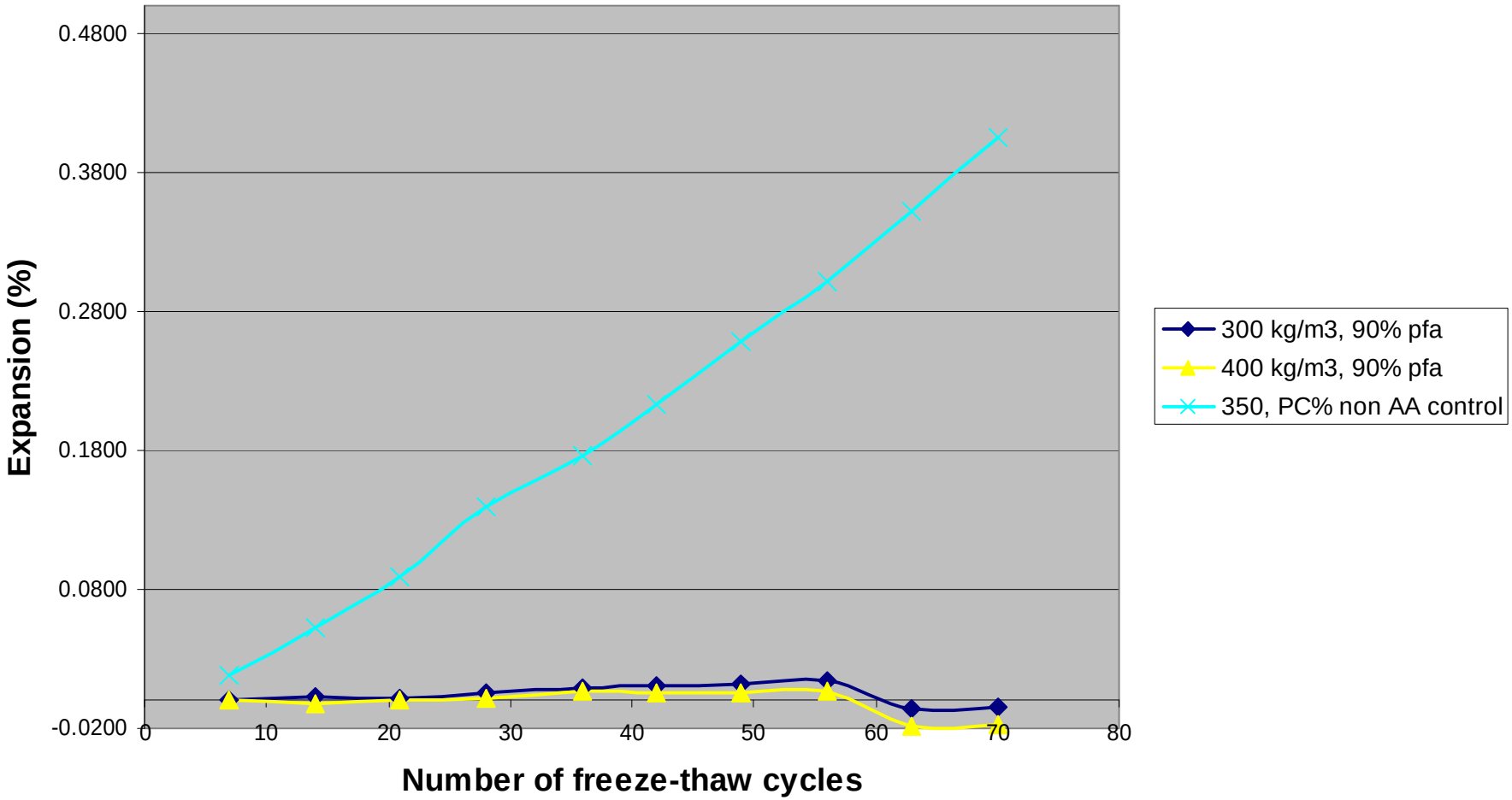
Alkaline ash binder concrete: 15 months in Class 4a sulfate solution



Frost resistance



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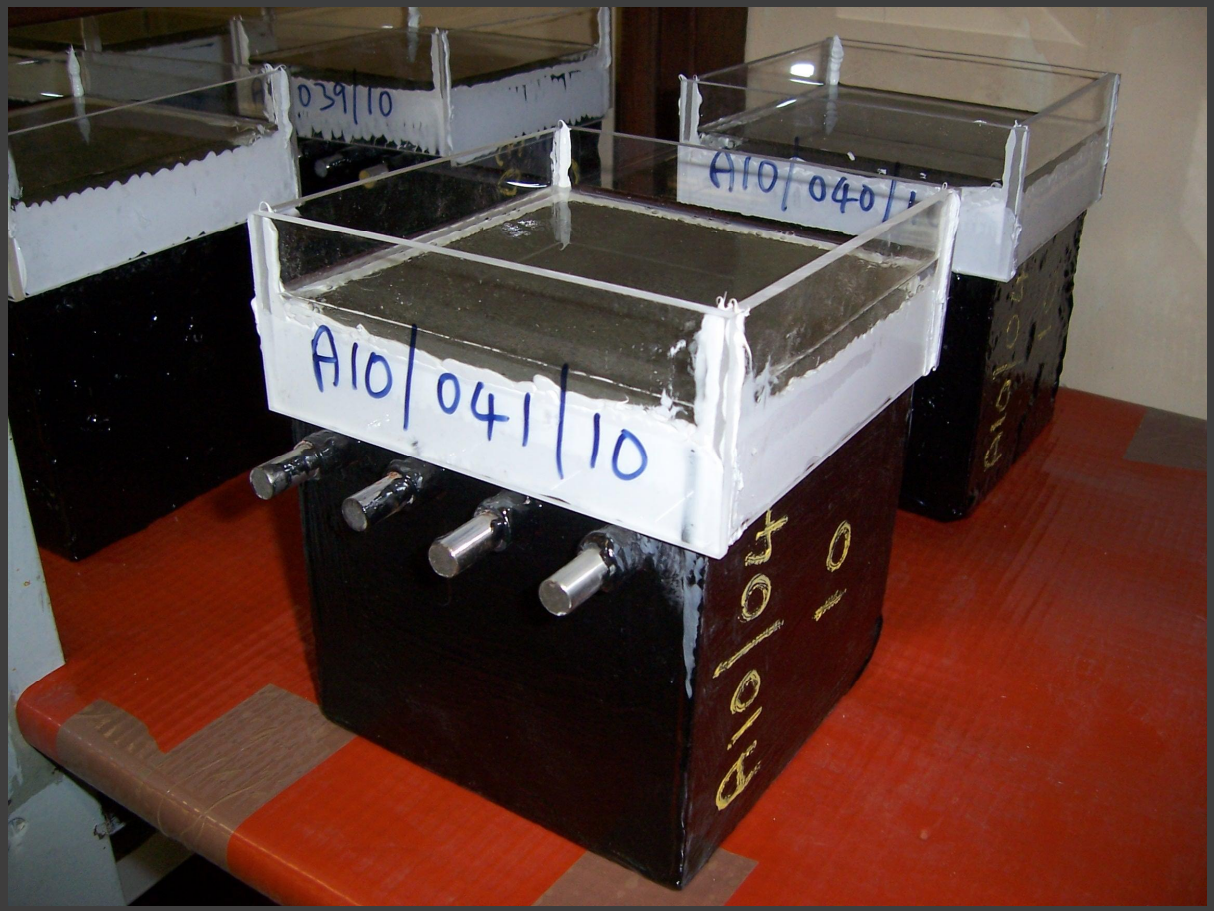
Freeze thaw

Freeze thaw

Freeze thaw

Reinforcement corrosion



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Alkali silica reaction: 300 mm cubes

Big specimens !!

Big specimens !!

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Big specimens !!

Life Cycle Analysis (LCA)

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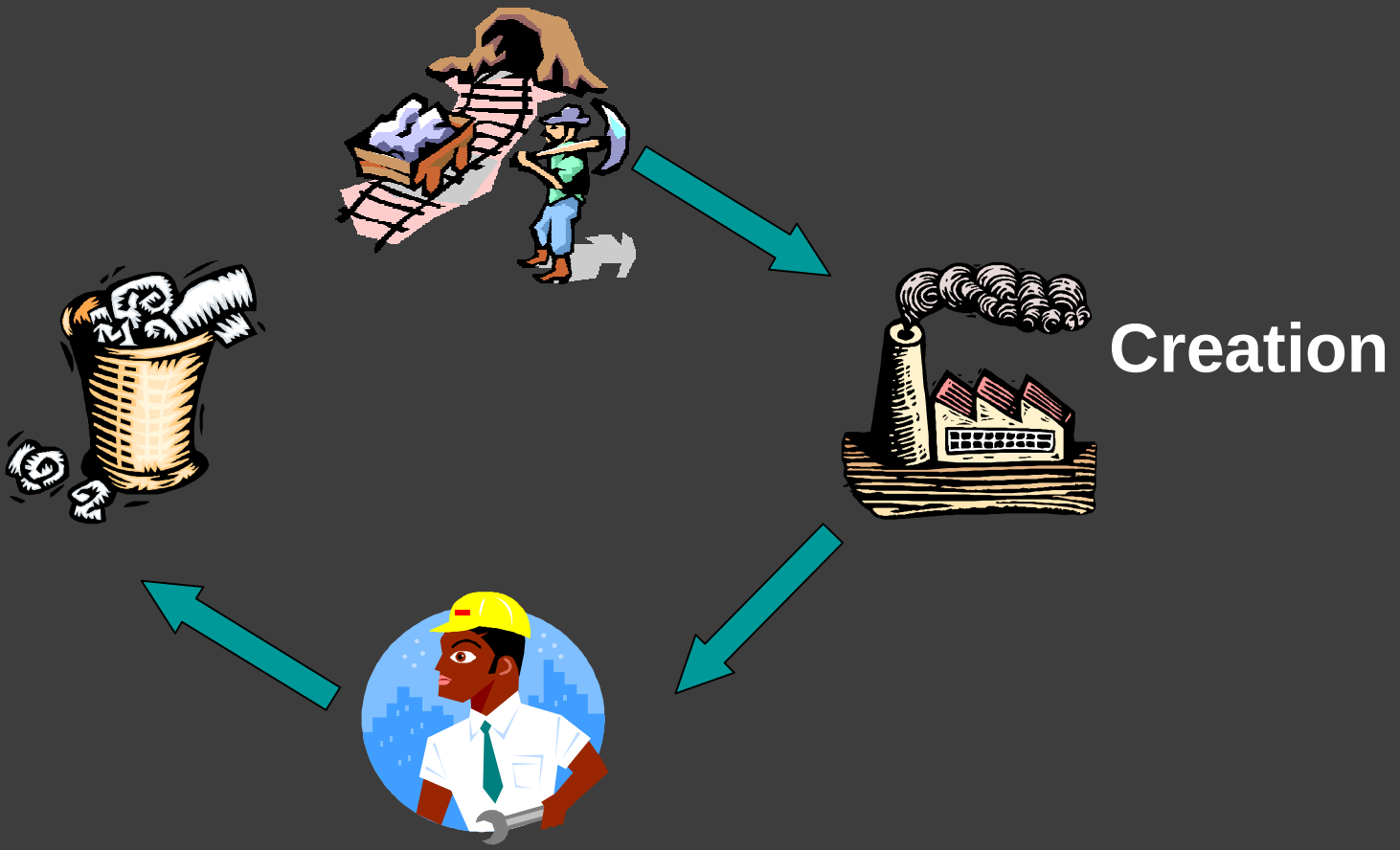
Simple example of LCA thinking



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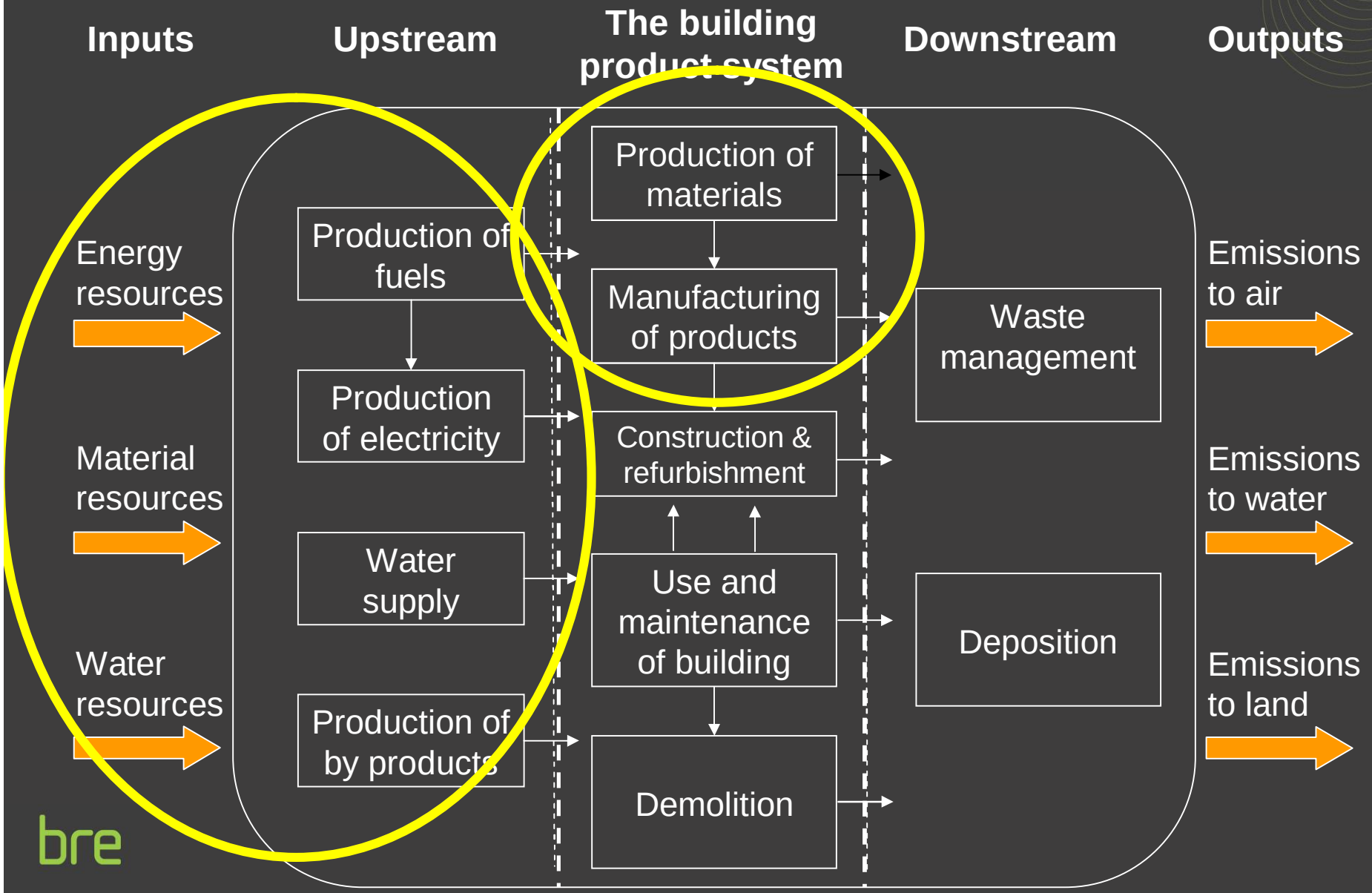
Life Cycle Analysis in Construction



Life cycle assessments in the literature: (Weil and co-workers)

- LCA of an alkali activated binder concrete formulation compared with a PC concrete with broadly similar compressive strength and durability (freeze-thaw resistance).
- Assessment (from “cradle to gate), showed:
  - Comparable resource depletion impacts for both formulations
  - Much less global warming impacts (the impact for the activated binder concrete was approximately 70% lower than the PC concrete)
  - Most global warming impacts from the chemical activators
  - Thermal curing can also significantly increase global warming impacts

  - Weil, M. and co-workers. Life cycle assessment of geopolymers. (Chapter 10 in Geopolymers: structure, processing, properties and industrial applications (Provis and van Deventer)

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Applications

- Pre-cast pavers, slabs, pre-cast panels and roof tiles
- Rapid pavement repair materials
- Heat resistant applications
- Waste immobilisation

- *one technology that may be utilised by cement and concrete product manufacturers to offer a broader range of products onto the market.*
- *Most well developed in pre-cast sector where safe handling of chemical activator can be more easily controlled*

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Barriers overcome

- Industrial-scale work and fundamental studies conducted over the past 50 years have demonstrated performance and durability but detailed knowledge is concentrated in a small number of individuals.

Remaining barriers to commercialisation

- Requirements of prescriptive standards. New binders (without PC) may perform acceptably but may not conform exactly to established regulatory standards, particularly in terms of composition and mix proportions
- Lack of long term durability data for normal environments over a period of decades
- Perceived unfamiliarity and complexity (eg confusing nomenclature, chemical complexity),
- Wide range of possible binder and activator formulations and resulting range of performance that can be achieved.

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Concrete block paver trials

- Three industrial trials at Marshalls' commercial concrete block paving plant at Maltby, Yorkshire.
- Run-of station pfa and calcareous component as binders.
- Semi-dry pressed industrial process. Each concrete trial batch had a volume of approx half a cubic metre and a weight in excess of 1 tonne.

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Paving flags

- Wet vibration process
- Two tonnes of concrete- full scale plant
- Good finishing characteristics
- Good performance: strength, polishing, skid resistance

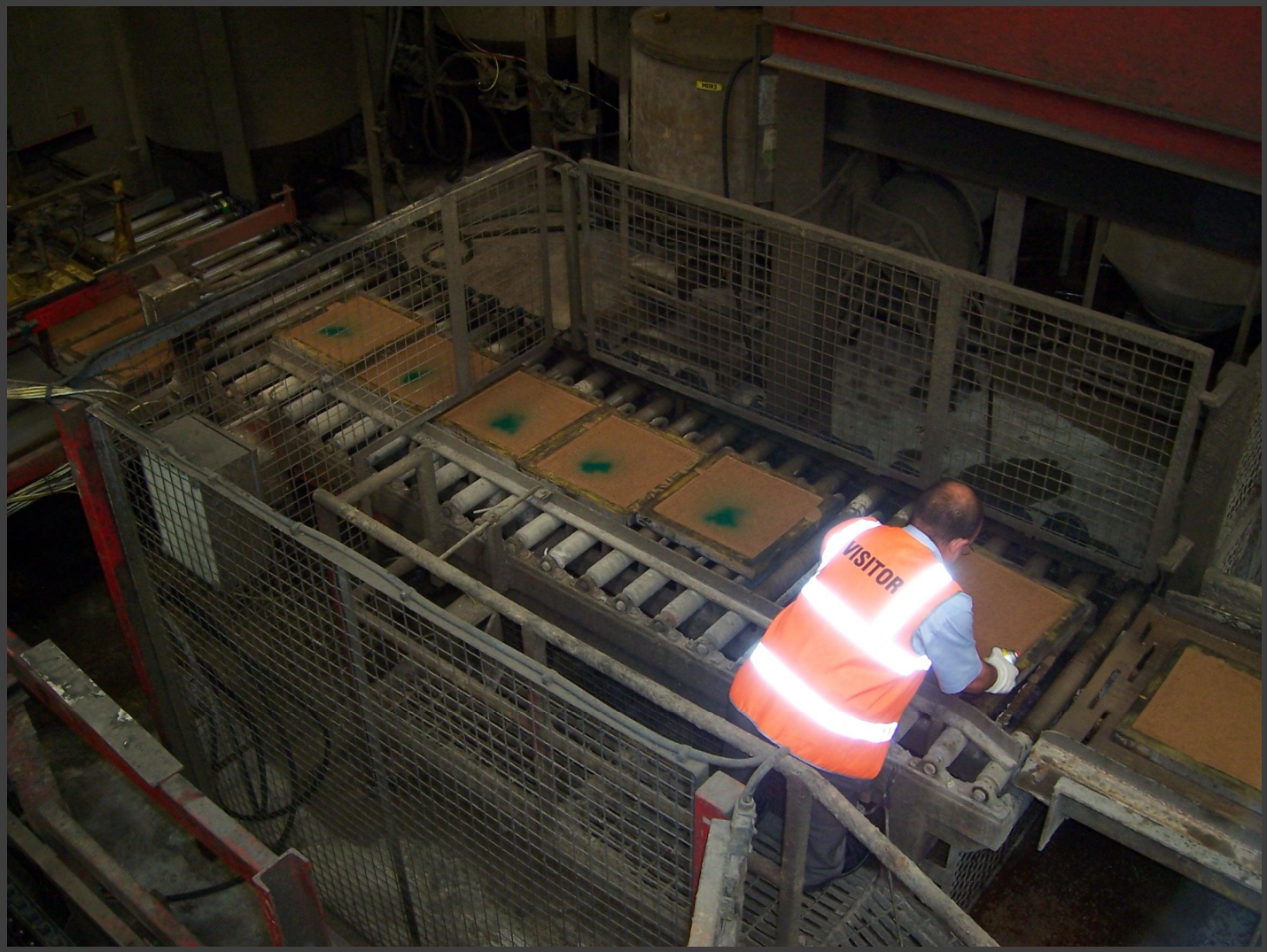
Production plant/mixer

Addition of powder

Mould stack

Mould filling

Compaction/marking



Stacked product in moulds

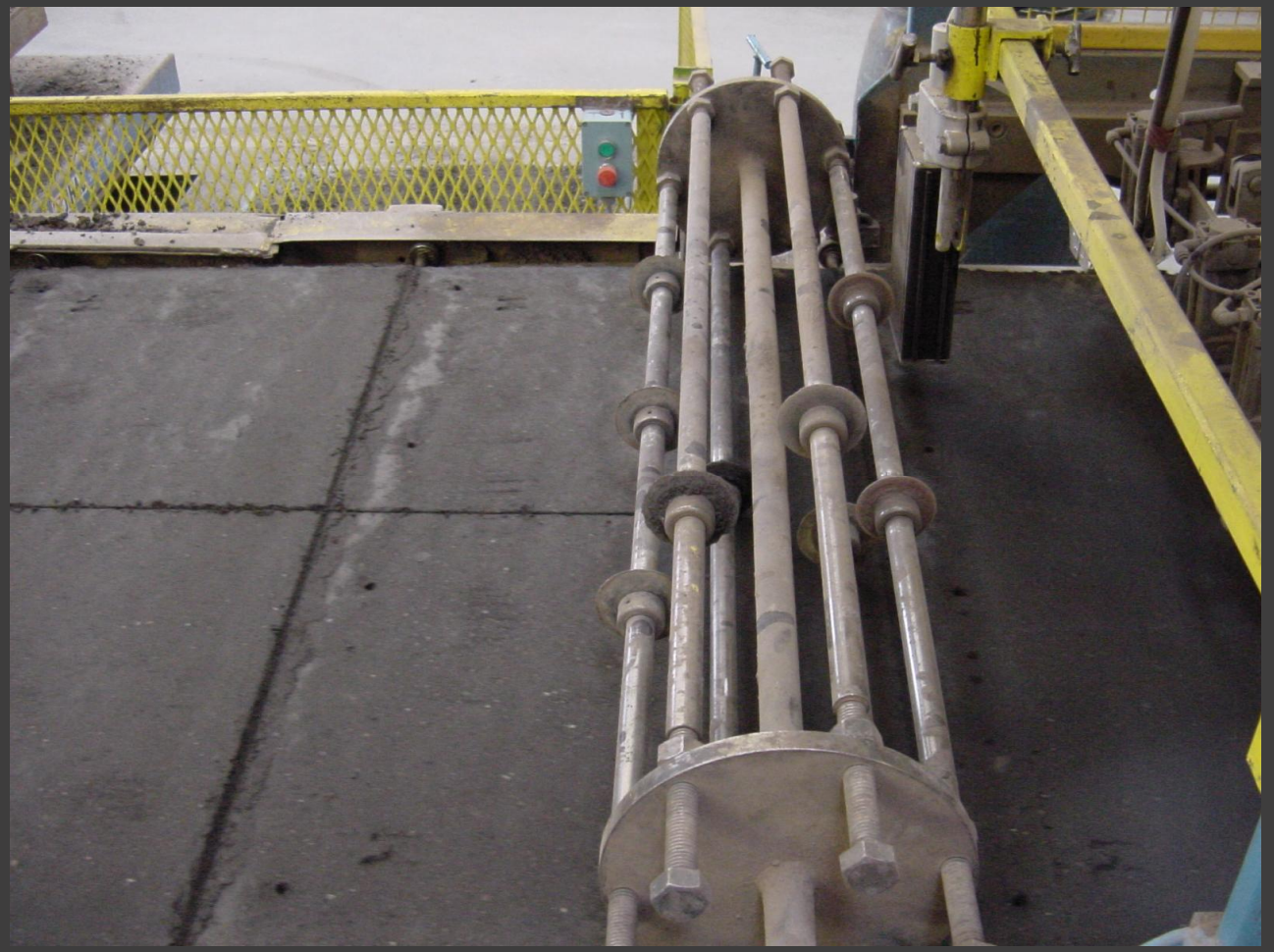
Finished product after demoulding

Hardrow® slates

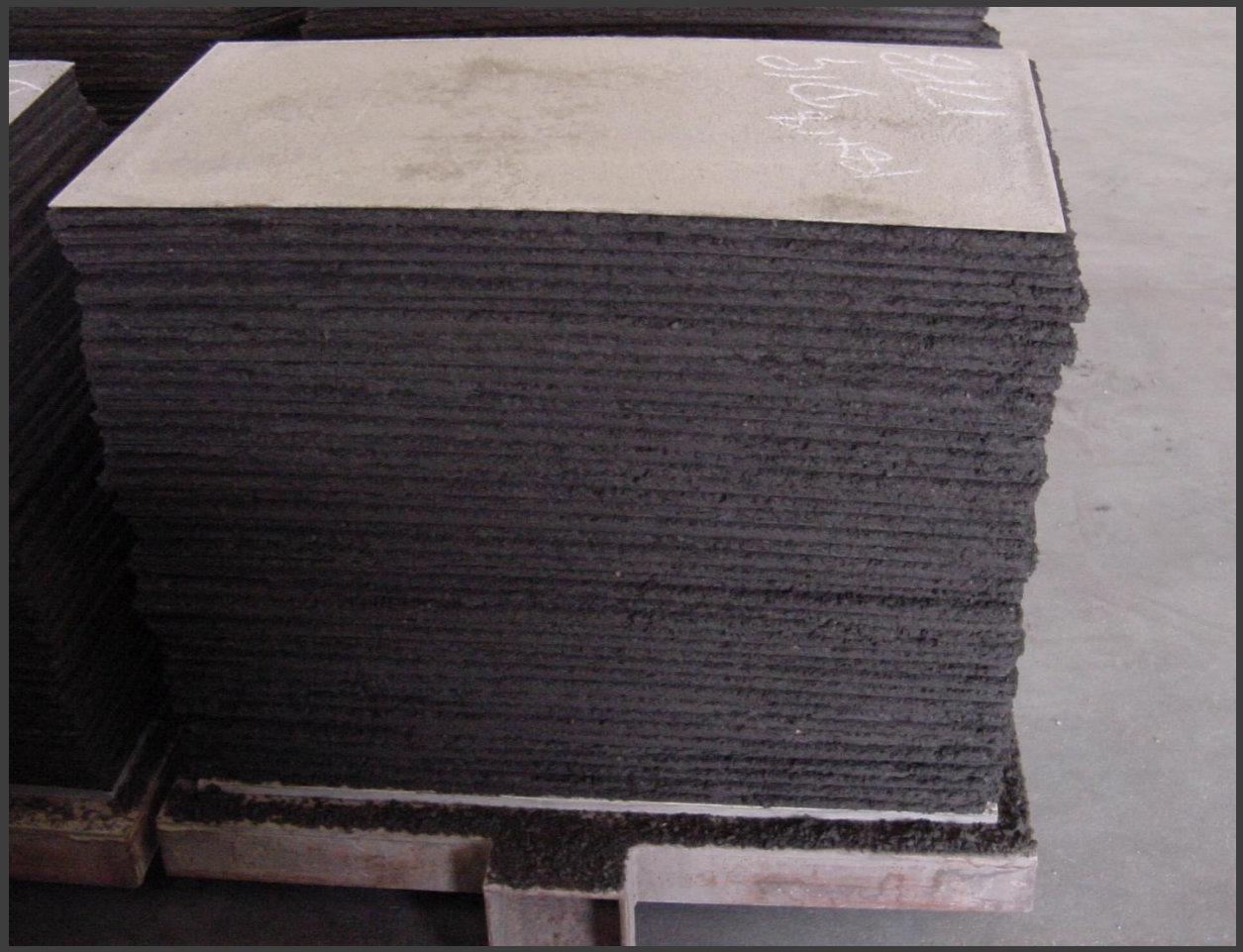
- Semi-dry process- roller compaction
- Full scale plant
- Backing and topping mixes
- Good performance- passed all acceptance tests- strength, dimensions, permeability, freeze-thaw

Slate machine top mix

Slate machine “sizer” cutting slates to size



Stack of finished slates



Activated binder products - High value, low CO_2

Concrete paving slabs and Hardrow ® slates made from activated binders (Courtesy of Marshals and CRH)

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BRE exposure site

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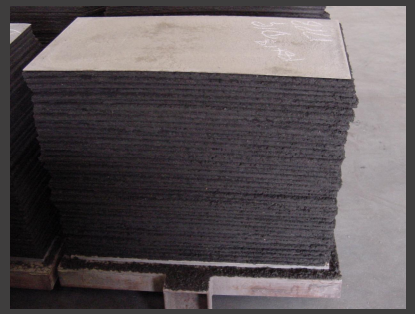
Global warming impacts from industrial products in current trials

- Impacts approx 25-30% of PC concrete equivalents (paving flags and artificial roofing slates)
- Impacts approx 50% of PC concrete equivalents (concrete block pavers)



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Future developments

- “one pack” formulations
- Safer activator formulations
- Codes and standards
- Formulations with lower activator content
- Handle-ability issues- setting time etc
- Establish a track record…….

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The Old Bridge at Axmouth over the River Axe The oldest concrete bridge in England. 1877

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Activated binder concrete

Alkali activated binders are a novel type of cement system with a significant benefits relative to Portland cements including:

- Binders produced from readily available waste / by-product materials such as power station and related ashes - without the need for the clinkering processes used for PC.
- High early strength
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