Imperial College London

Annual Hong Kong Concrete Seminar 2022
Low-carbon concrete on the move

Low-carbon and carbon negative cement and concrete
A vision for the future

Christopher Cheeseman

Professor of Materials Resources Engineering
Director of the Centre for Infrastructure Materials
UKCRIC Advanced Infrastructure Materials Laboratory
Head of the Materials Section
Department of Civil and Environmental Engineering
Imperial College London

Standing Committee on Concrete Technology (SCCT)

HKIE THE HONG KONG INSTITUTION OF ENGINEERS 香港工程師學會

Fundamental to research across the Department

RESEARCH AREAS

Low-carbon sustainable infrastructure

New cements, 3D printed metals, industrial ecology

Long-term durability and performance

Concrete durability, fracture mechanics, service life prediction

Functional and improved materials

New types of permeable pavement, durable super-hydrophobic surfaces

Circular economy

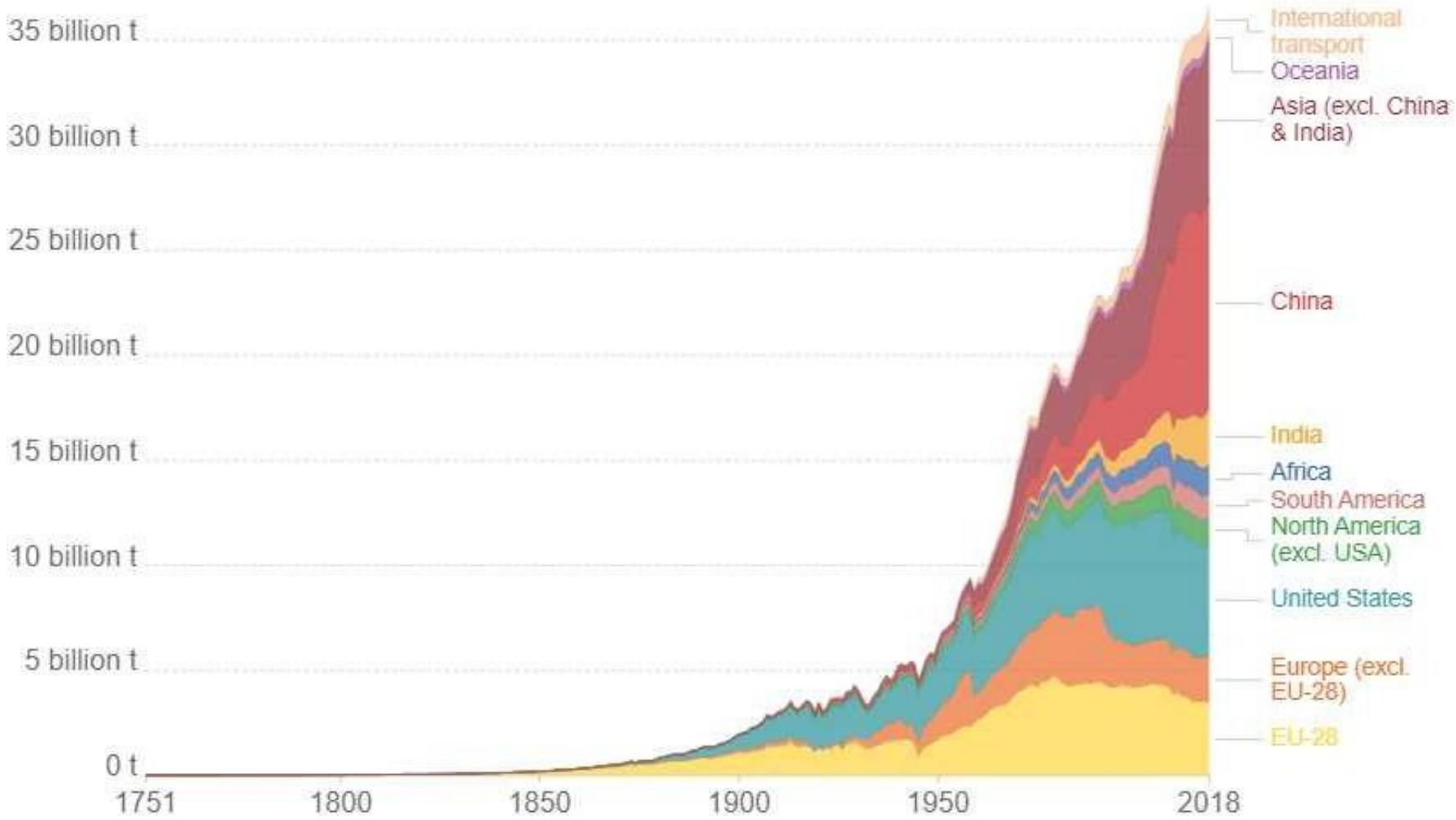
Novel thermal insulation materials, new biomaterials, ceramic processing, plastics in the oceans

- ✓ **Whole life cycle issues**
- ✓ **Addressing major global materials challenges**

MSc Course
Advanced Materials for Sustainable Infrastructure

Imperial College London

Annual total CO_2 emissions by world region



Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)
Note: 'Statitistical differences' included in the GCP dataset is not included here.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

Cement production

Global Cement production

Main world producers - The G-20 Group

Cement production (Million tonnes)

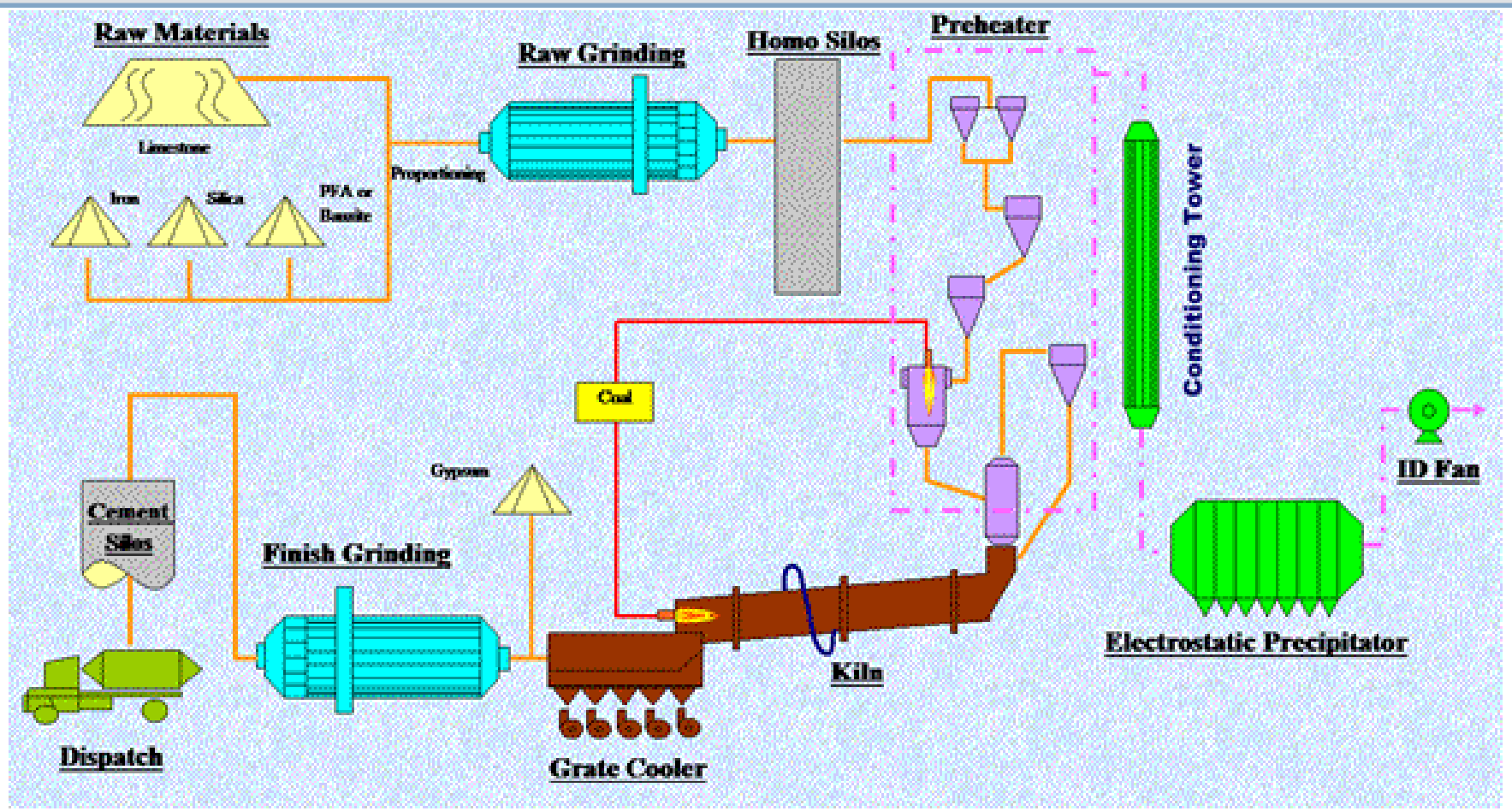
Country	2001	2005	2010	2015	2016	2017	2018	2019	2020
China	661.0	1 079.6	1 881.9	2 350.0	2 403.0	2 316.3	2 176.7	2 300.0	2 376.9
India	102.9	146.8	220.0	270.0	289.3	285.0	327.7	320.0	290.0
EU28 *	225.6	251.1	192.1	167.2	169.1	175.1	179.8	182.1	171.5
USA	88.9	99.4	65.2	83.4	84.7	86.1	87.8	88.6	89.0
Brazil	39.4	39.2	59.1	72.0	57.6	54.0	53.5	53.4	60.6
Turkey	30.0	45.6	62.7	71.4	75.4	80.6	72.5	57.0	72.3
Russian Federation	28.7	49.5	50.4	69.0	55.0	54.7	53.7	54.1	56.0
Indonesia	31.1	36.1	39.5	65.0	61.3	68.0	70.8	64.2	64.8
South Korea	52.0	49.1	47.4	63.0	56.7	57.9	55.0	56.4	48.0
Japan	79.5	72.7	56.6	55.0	53.4	55.5	55.3	55.2	52.1
Saudi Arabia	20.0	26.1	42.5	55.0	55.9	47.1	42.2	42.2	53.4
Mexico	33.2	38.1	34.5	39.8	42.4	42.8	42.8	47.5	41.9
Germany	32.1	31.9	29.9	31.1	32.7	34.0	33.7	34.2	35.5
Italy	39.8	46.4	34.4	20.8	19.3	19.3	19.3	19.2	18.1
France	19.1	21.7	18.0	15.6	15.9	16.9	16.5	16.5	16.7
South Africa	8.4	12.1	10.9	14.0	13.6	13.2	12.5	12.4	13.2
Canada	12.1	13.5	12.4	12.5	11.9	12.7	13.3	13.4	13.0
Argentina	5.5	7.6	10.4	12.2	10.9	12.0	11.8	11.5	9.9
United Kingdom	11.9	11.6	7.9	9.6	9.4	9.4	9.2	9.1	8.0
Australia	6.8	9.1	8.3	9.3	10.0	10.0	9.8	10.0	9.6

**EU27 data is compiled using latest available data - EU28 until 2019 / EU27 as of 2020 reporting year*

Sources: CEMBUREAU, US Geological Survey, Global Cement Report, Global Cement Directory

Global cement production in 2021 was 4.2 billion tonnes

Carbon emissions associated with Portland cement

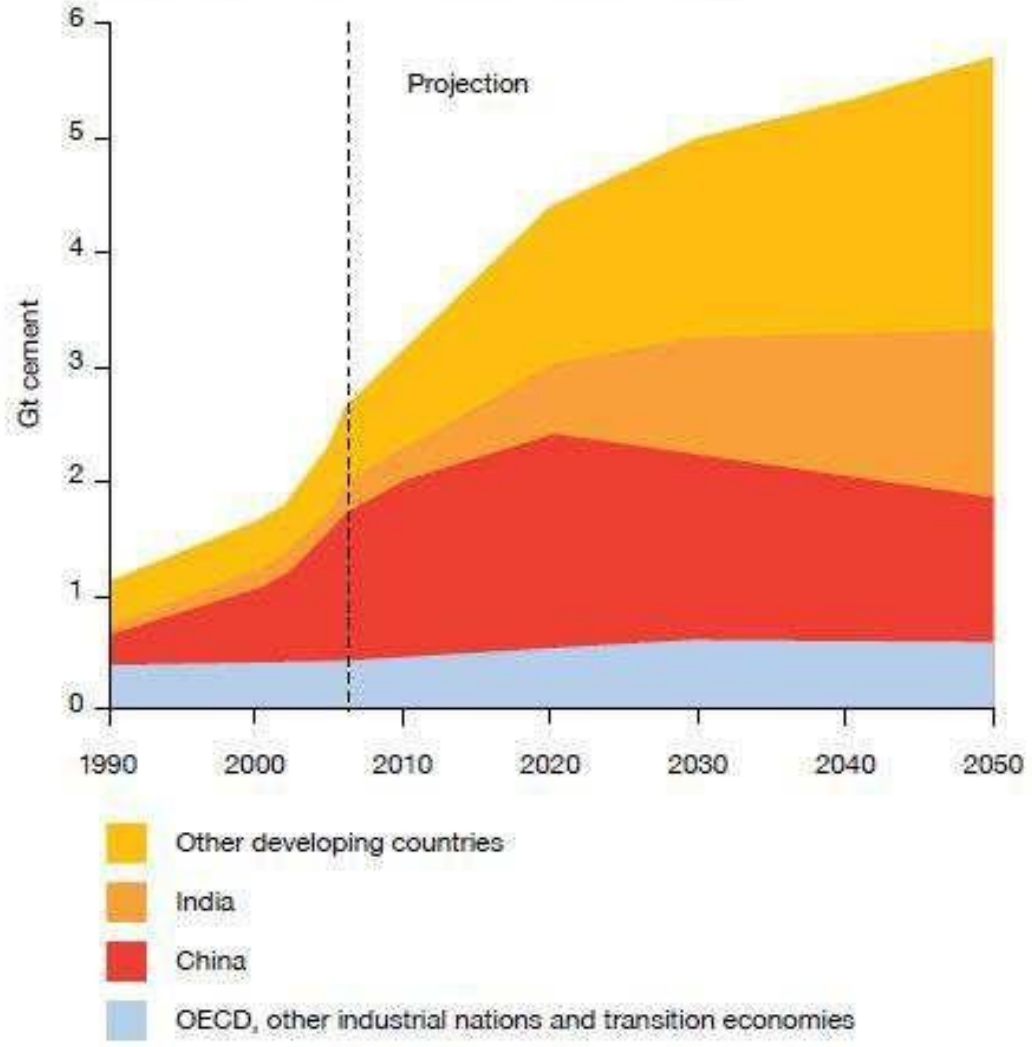


Kiln temperature of 1450 degrees C

Decomposition of limestone ($CaCO_3$) with release of CO_2

Modern cement plants produce ~ 650 Kg CO_2/tonne of cement

Cement production - the near future



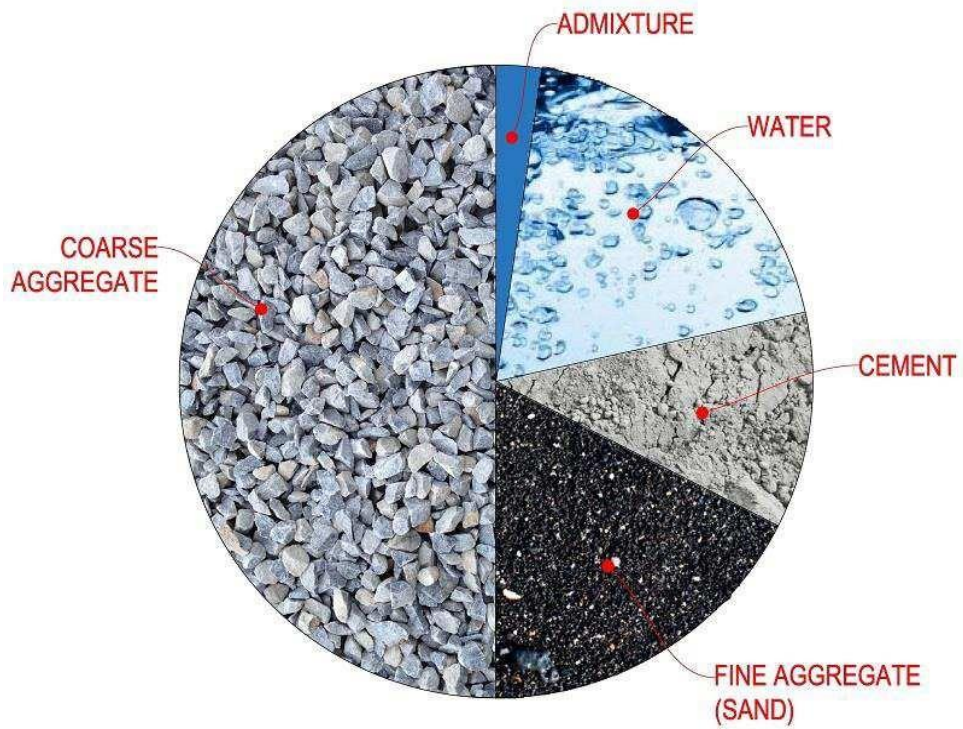
2022, ~ 2.73 billion tonnes of CO_2

2050, ~ 4.00 billion tonnes of CO_2

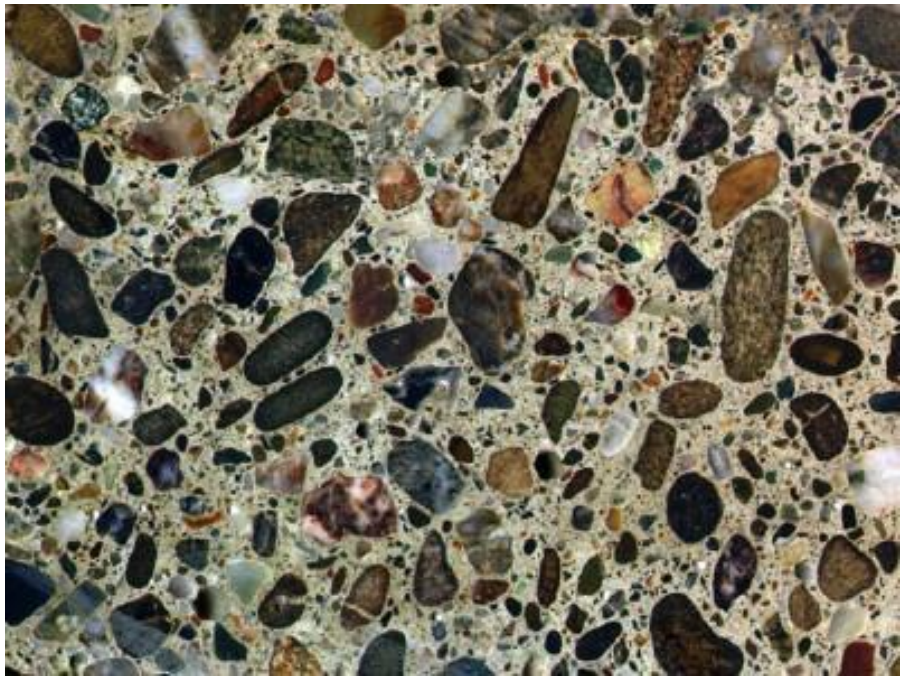
2025 ~ $ 680 billion business

~ 8% of all human CO_2 emissions

Concrete



Concrete mix design



Concrete microstructure

Concrete is just an amazing low-carbon material

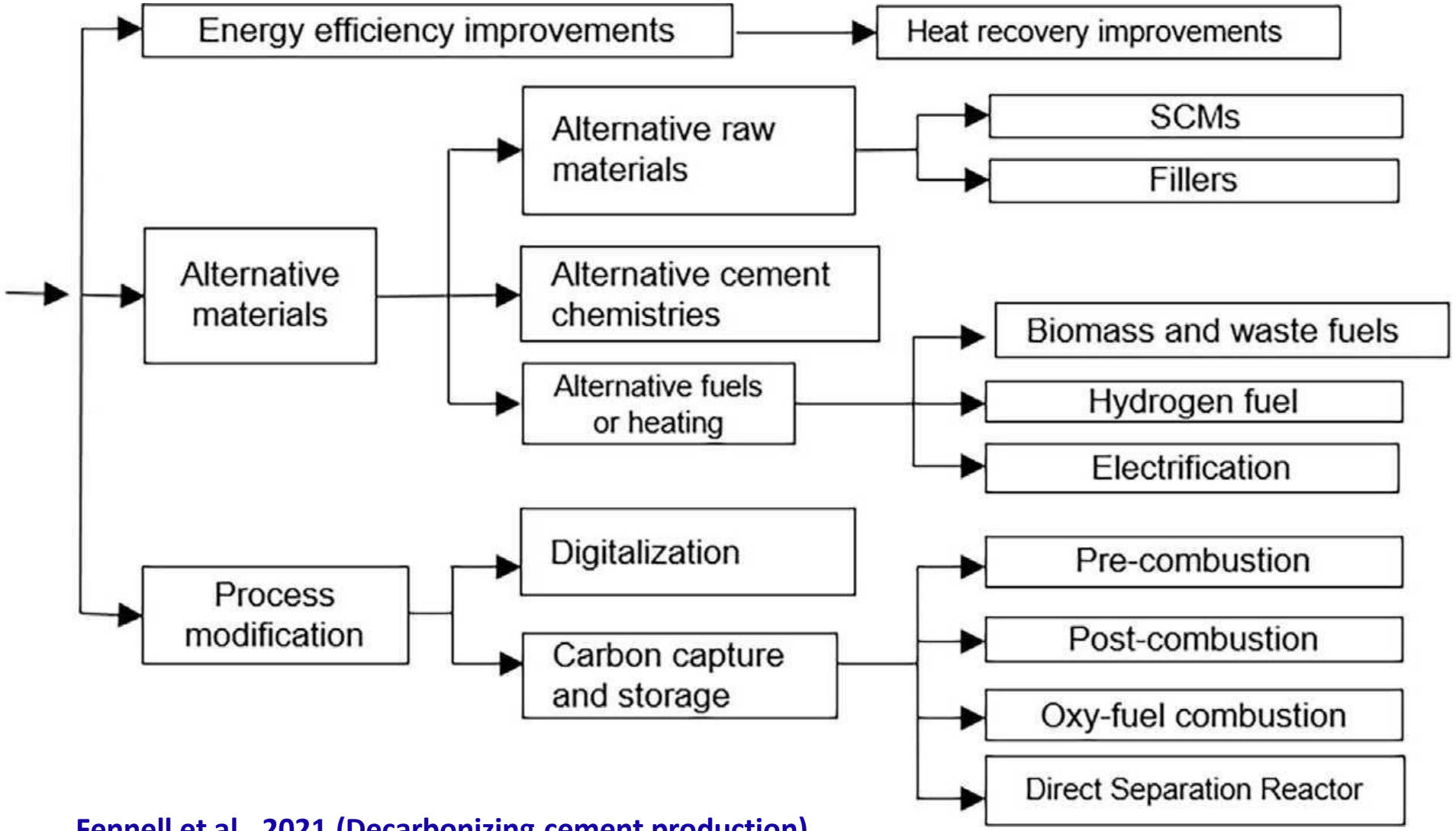
Transport infrastructure

Clean water and sanitation

Cities

Issue with the appreciation by the general public of the contribution of civil engineering and particularly concrete to sustainable development.

Decarbonising cement production



Fennell et al., 2021 (Decarbonizing cement production)

Approaches to produce low-carbon cement

Supplementary cementitious materials (SCMs)

- Pulverised fuel ash (PFA)
- Ground granulated blast furnace slag (GGBFS)

Alternative biofuels including municipal solid waste (MSW)

Limestone calcined clay cements (LC3)

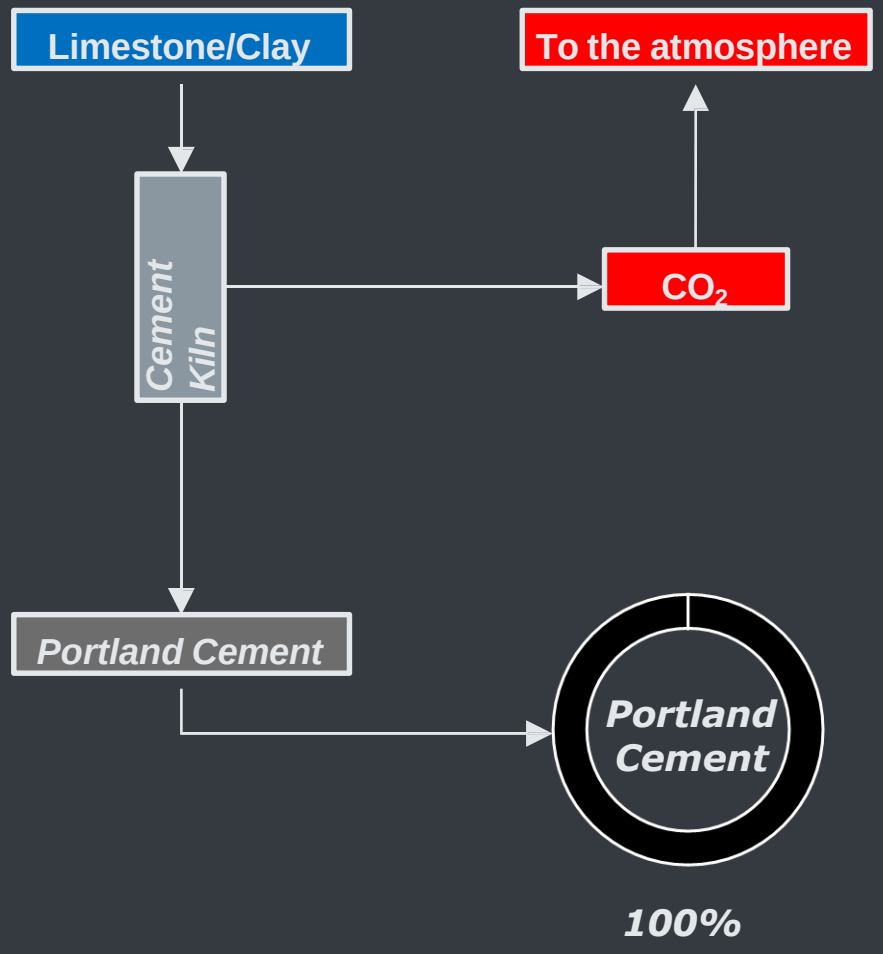
- Blended Portland cements
- Metakaolin (calcined kaolinite clay) and limestone
- Uses low-grade kaolinite clay with 15% of limestone
- Alumina from metakaolin reacts with limestone, reducing porosity
- Equal strength with high levels of clinker substitution

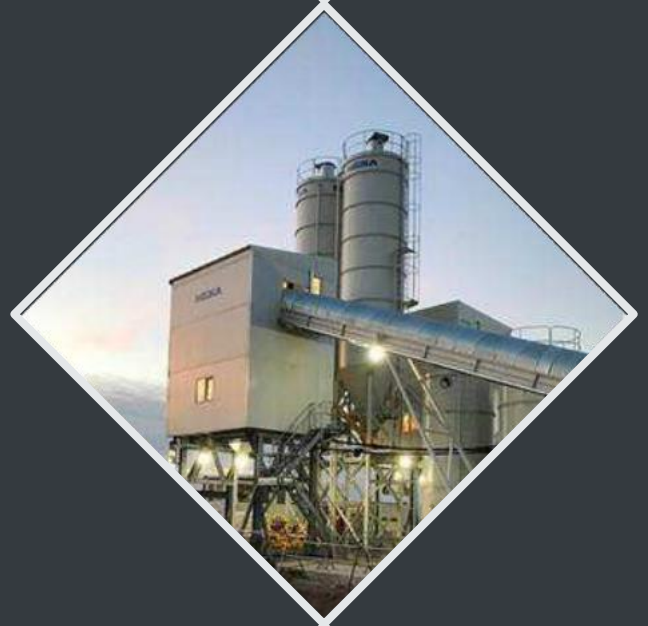
Carbon Capture and Storage (CCS)

Imperial College London

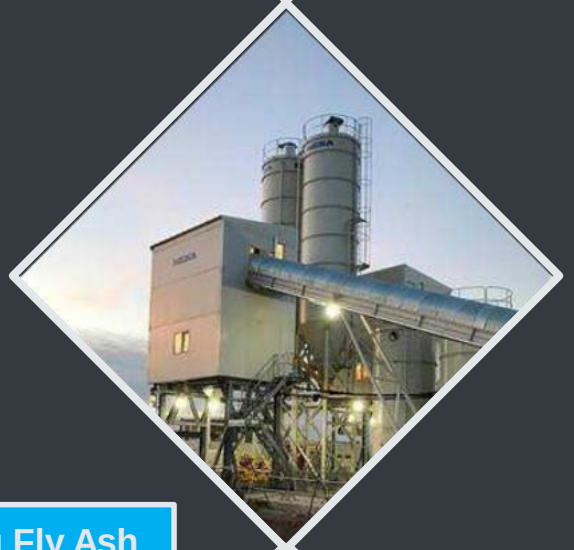
Limestone calcined clay cement LC3

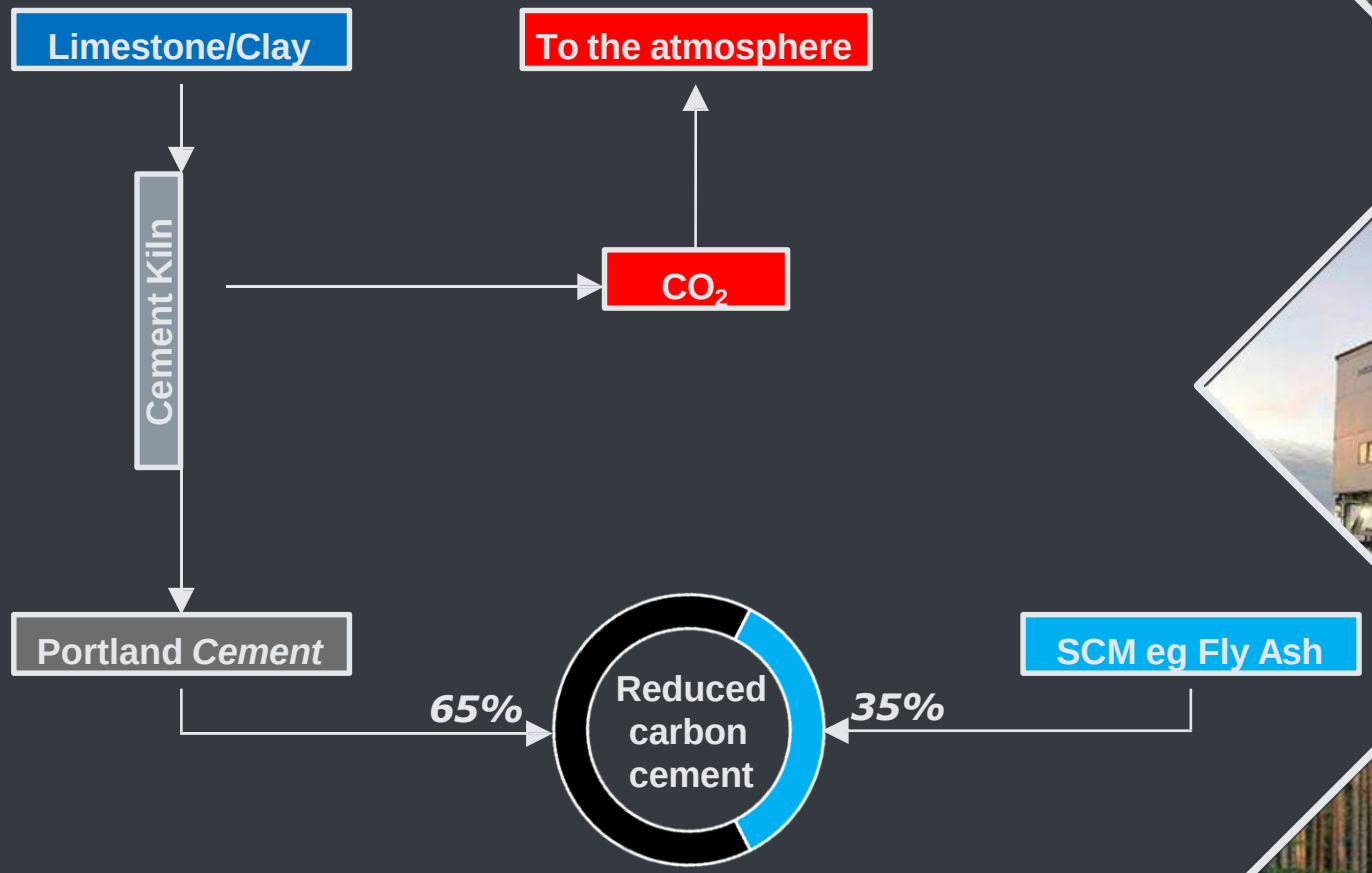
Portland Cement Production



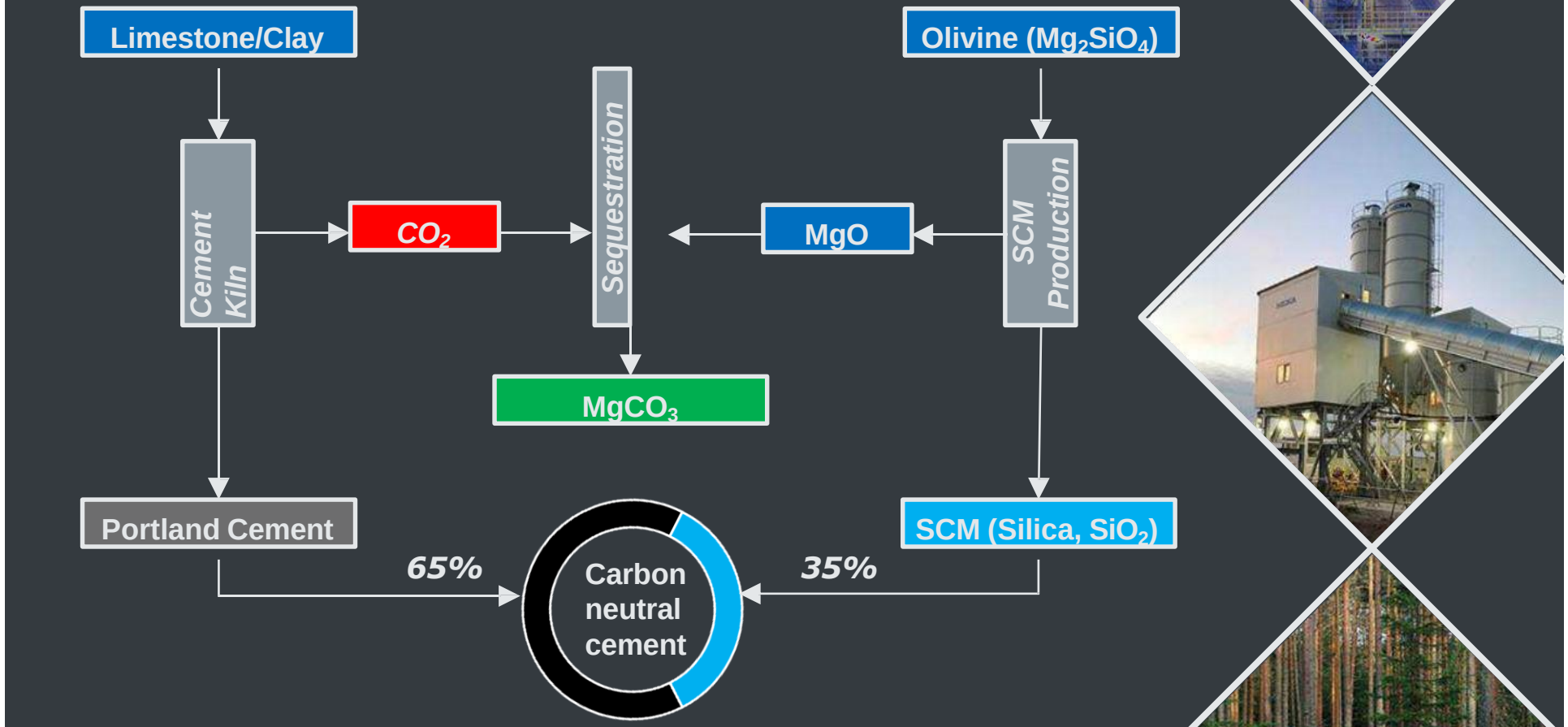


Reduced Carbon Cement using SCMs



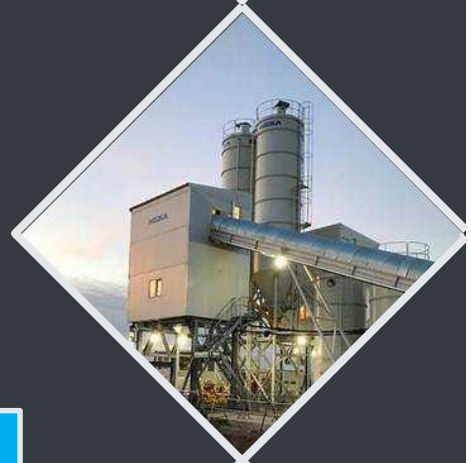


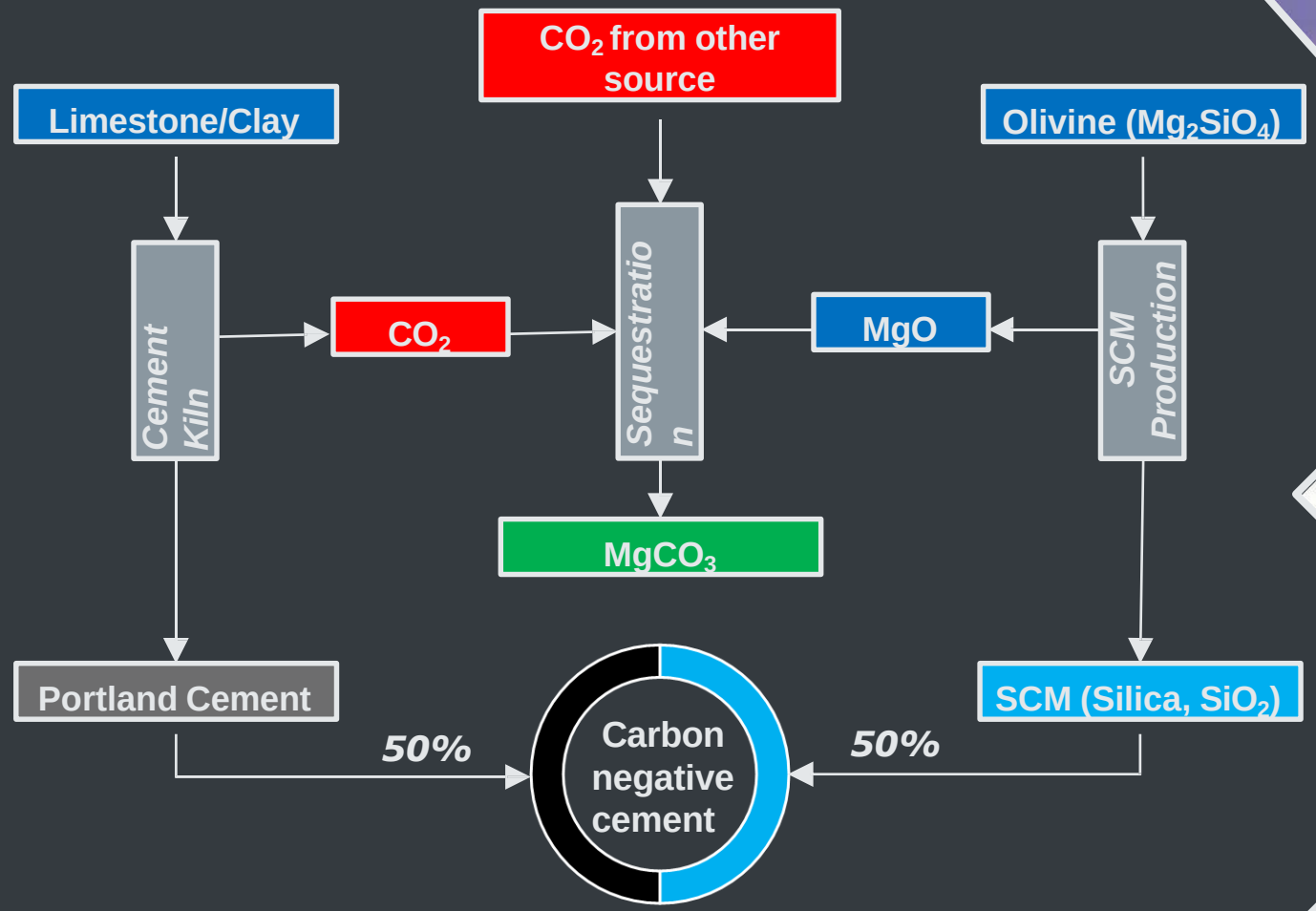
Seratech Carbon Neutral Cement



Seratech Carbon Negative Cement

SERATECH
SUSTAINABLE CEMENT SOLUTIONS





Seratech cement

Compatible with existing cement manufacturing

Uses magnesium silicates, major minerals found in the earth's crust

Produces a carbon negative supplementary cementitious material

Carbon sequestered to form $MgCO_3$ offsets cement production CO_2 emissions

Magnesium carbonate can be used to form other construction products

Reagents used in the process are reused

Process operates at low temperatures

Silica formed is a highly reactive

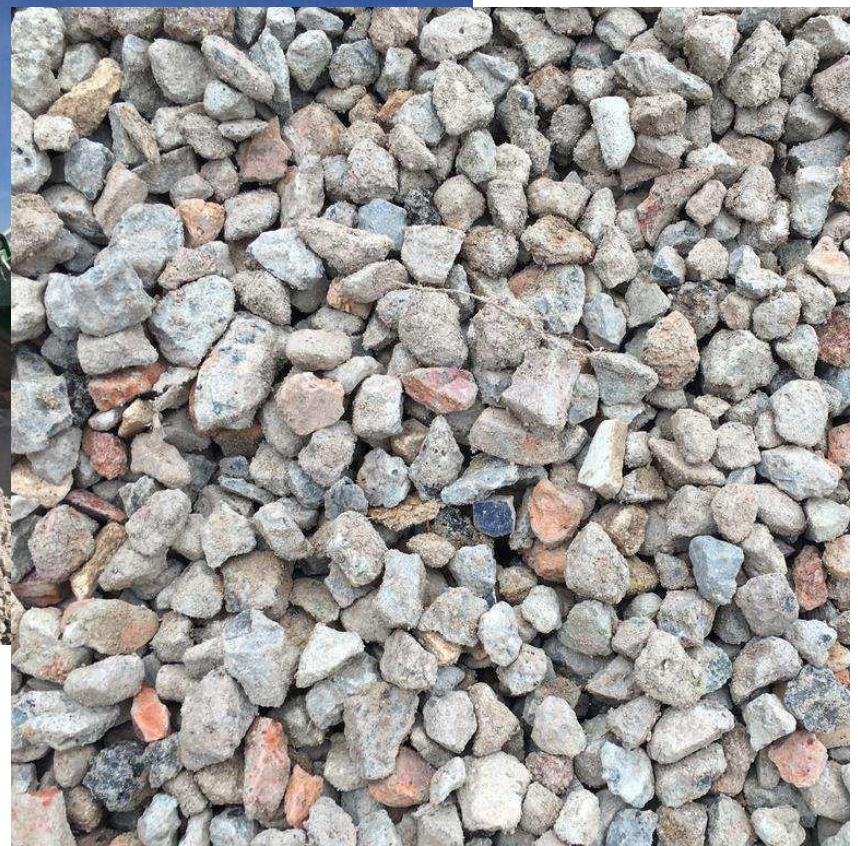
Imperial College London

Seratech carbon neutral cement blocks

Winner 2022 – OBEL AWARD

Imperial College London

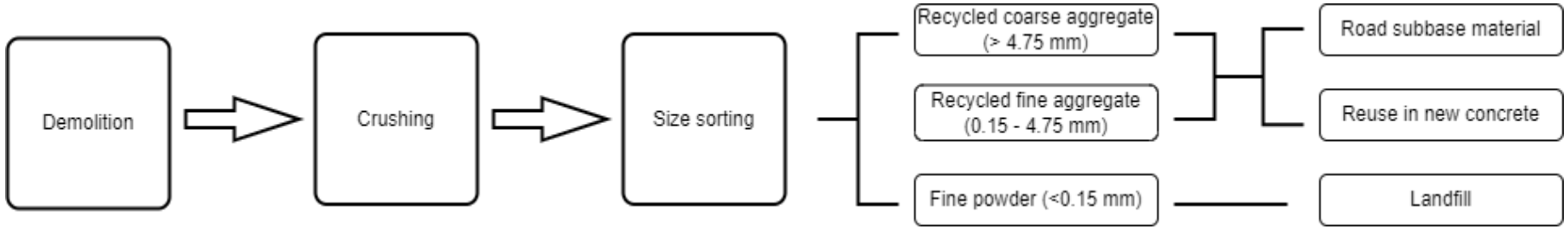
End-of-life concrete and carbon-negative aggregates

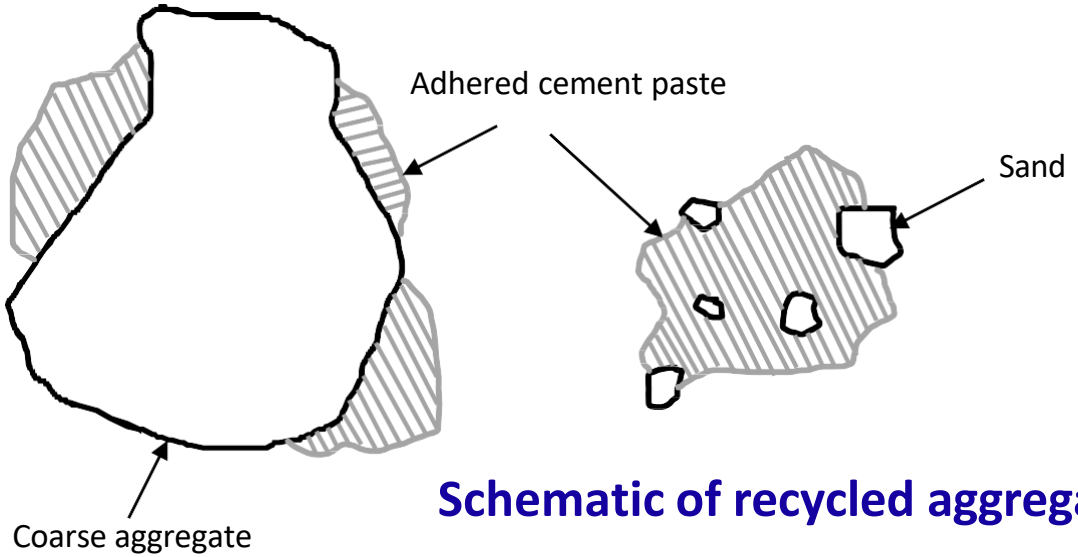


Waste concrete

Over 3.4 billion tonnes of waste concrete generated globally each year

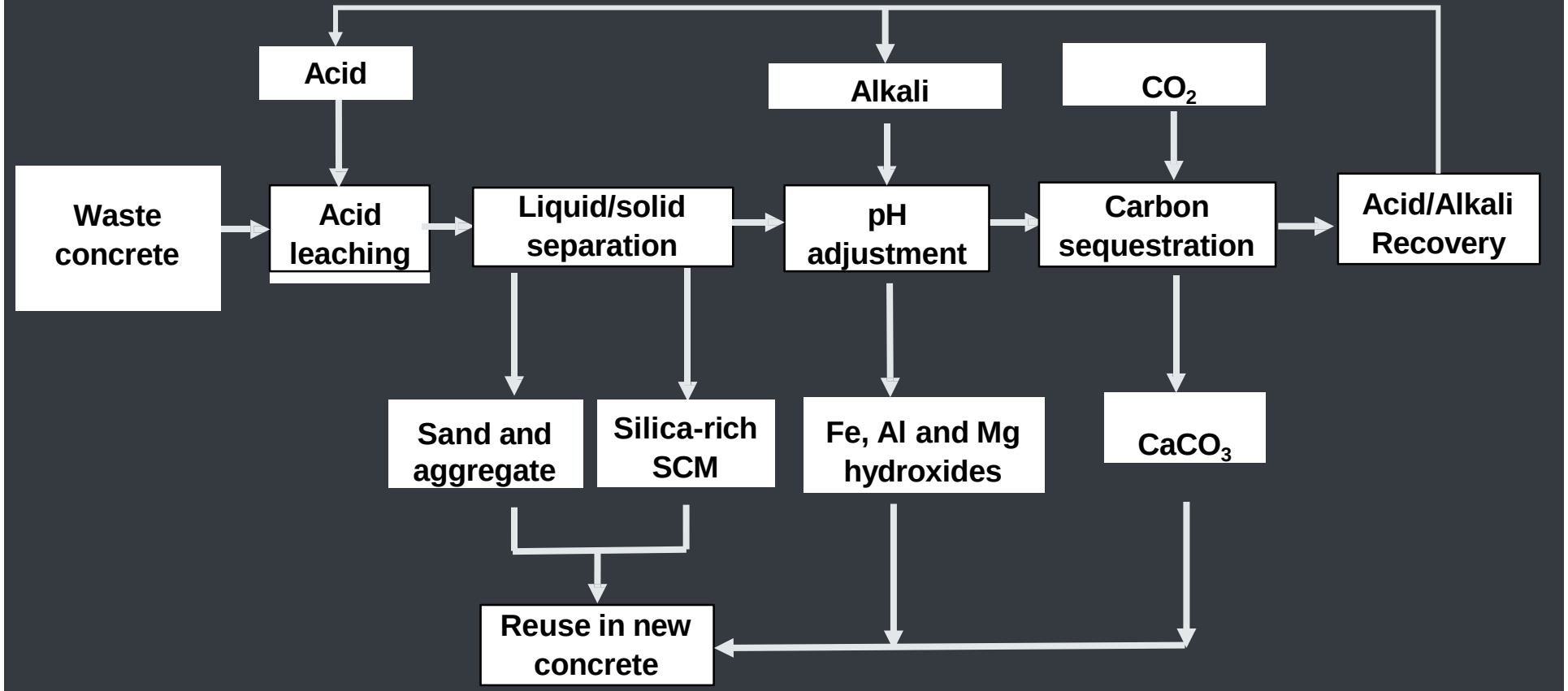
Current concrete recycling process - downcycling





Schematic of recycled aggregates

Advanced waste concrete processing overview



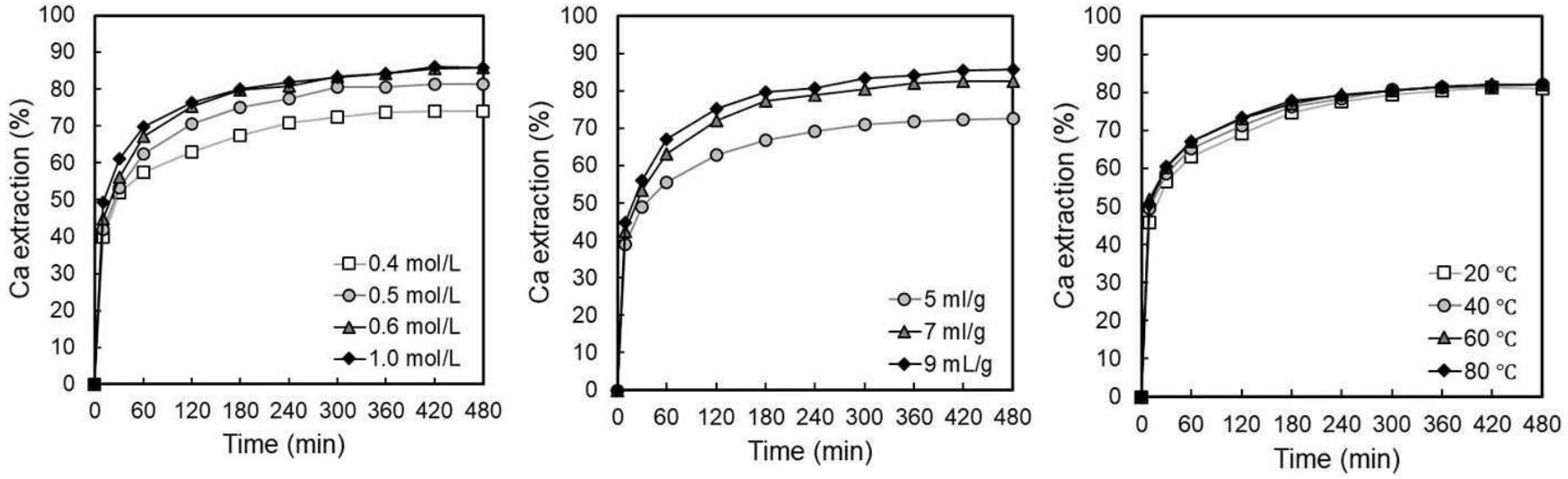
Producing clean sand and aggregate, a new silica based SCM and with carbon sequestration through the production of calcium carbonate.

Aims and objectives

Achieve low-carbon circular concrete through production of clean reusable sand and aggregate, a novel silica-based SCM, and vaterite with CO_2 sequestration

- optimize acetic acid leaching process of waste concrete
- assess acid treated properties of recycled fine aggregates
- assess the potential of silica-rich residue to be used as a SCM
- investigate the production and applications for vaterite

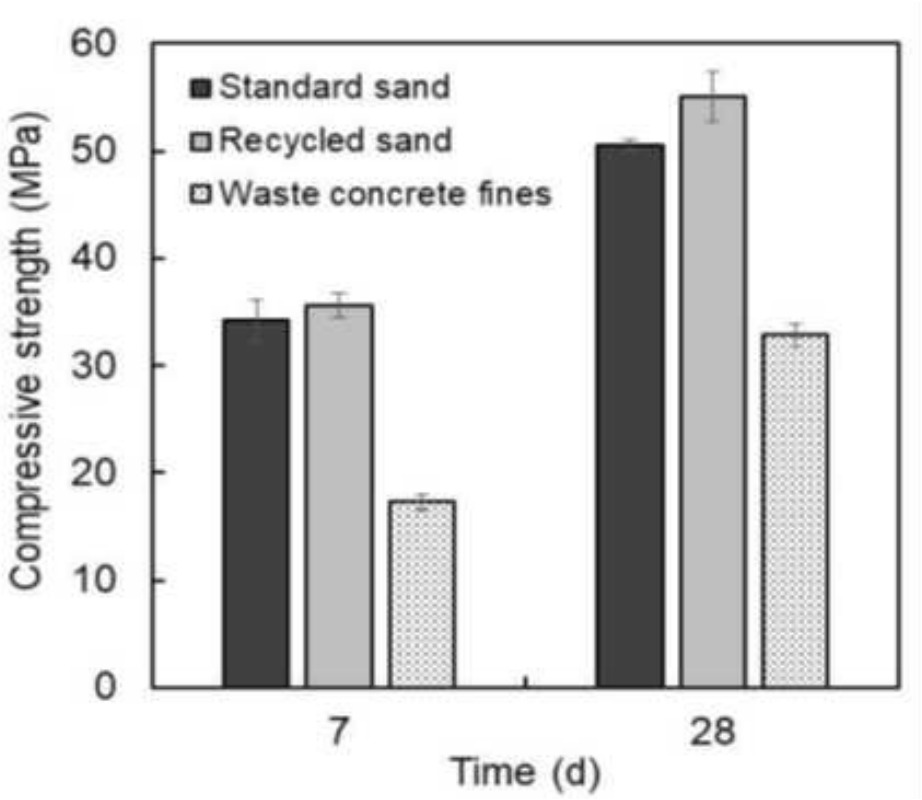
Optimising leaching conditions



Ca^{2+} extraction ratio with acetic acid concentration, liquid-to-solid ratio and temperature

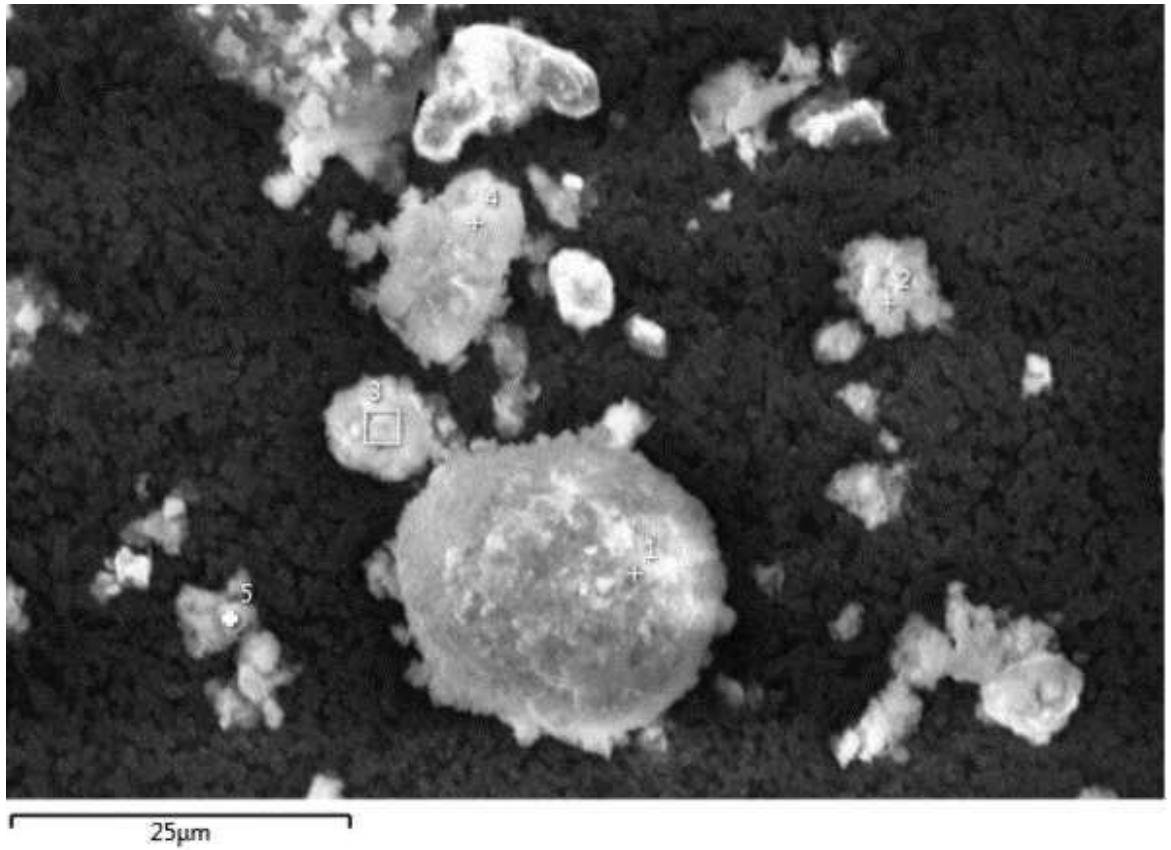
Optimal leaching: 0.6 mol/L acetic acid, L/S ratio 7 ml/g, ambient temperature for 6 hours

Clean sand and aggregate

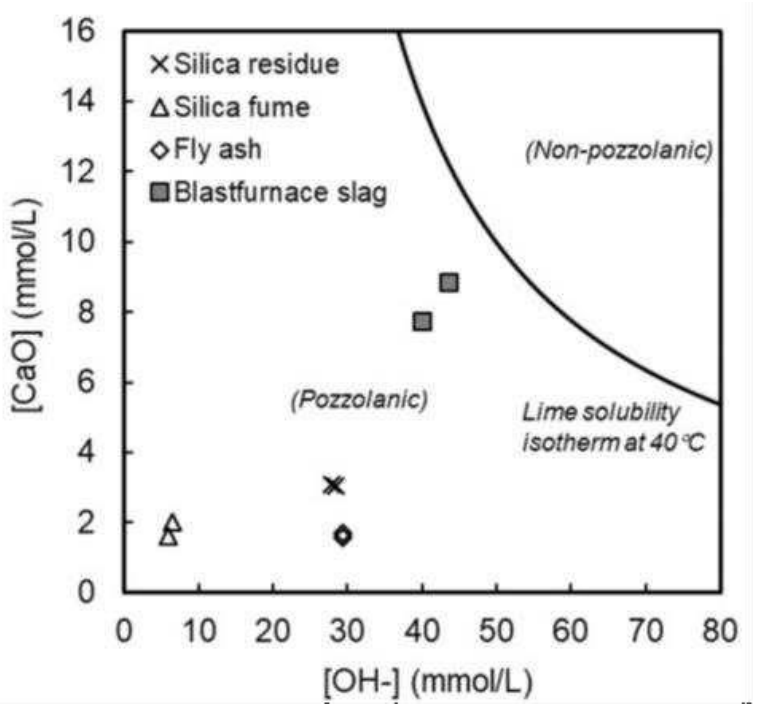


Compressive strength of mortars

Characterisation of silica-rich residue



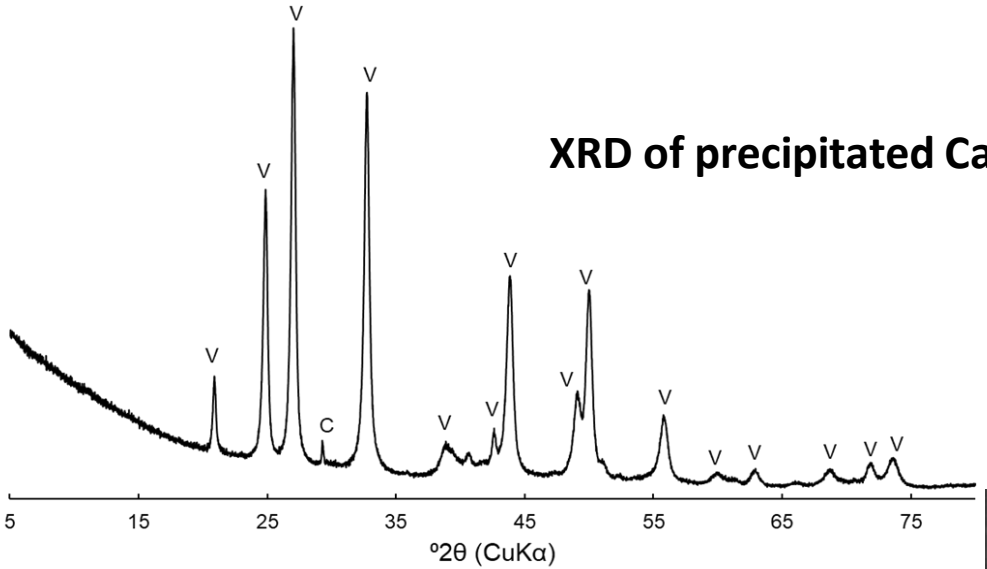
SEM-EDS image of silica-rich residue



Frattini test results

Alumino-silicate particles with pozzolanic activity similar to coal fly ash

CO_2 sequestration to form $CaCO_3$



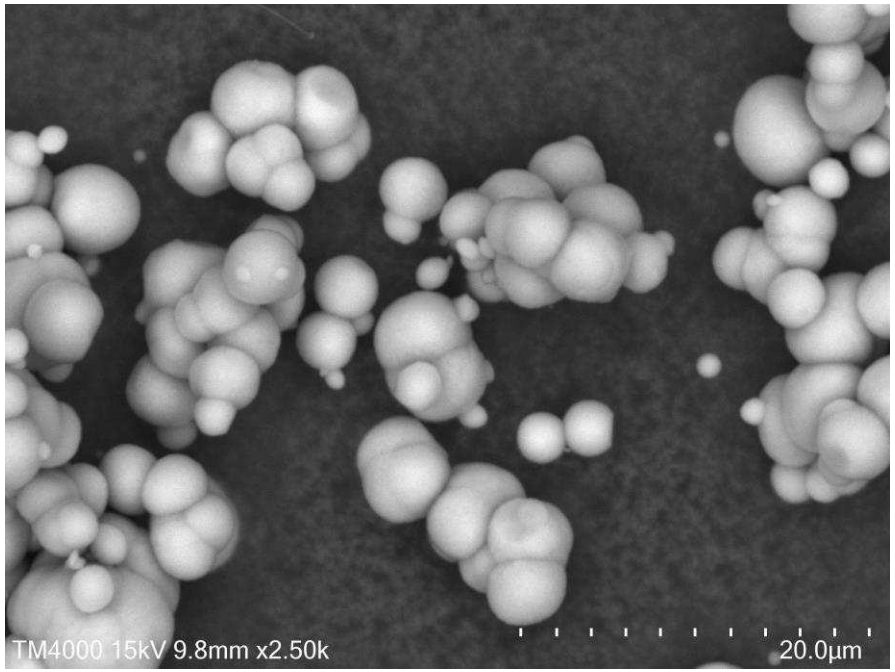
XRD of precipitated $CaCO_3$. V-vaterite; C-calcite

Production of vaterite

Conditions: 100% CO_2

Ambient temperature and pressure

Reaction time of ~20 minutes



SEM image of precipitated $CaCO_3$

Conclusions

Role of concrete in sustainable development

Huge issues associated with total carbon dioxide emissions

Reviewed options for managing emissions

SC3 cements and CCS will have a significant global role

Seratech - a potential way to make carbon negative cement

Circular concrete and the potential for carbon negative aggregates

Concrete has an amazing future - super carbon-negative concretes (SCNC)

Imperial College London

Annual Hong Kong Concrete Seminar 2022
Low-carbon concrete on the move

Low-carbon and carbon negative cement and concrete:
A vision for the future

Christopher Cheeseman

Professor of Materials Resources Engineering
Director of the Centre for Infrastructure Materials
UKCRIC Advanced Infrastructure Materials Laboratory
Head of the Materials Section
Department of Civil and Environmental Engineering
Imperial College London

Standing Committee on Concrete Technology (SCCT)

HKIE THE HONG KONG INSTITUTION OF ENGINEERS 香港工程師學會

Imperial College
London