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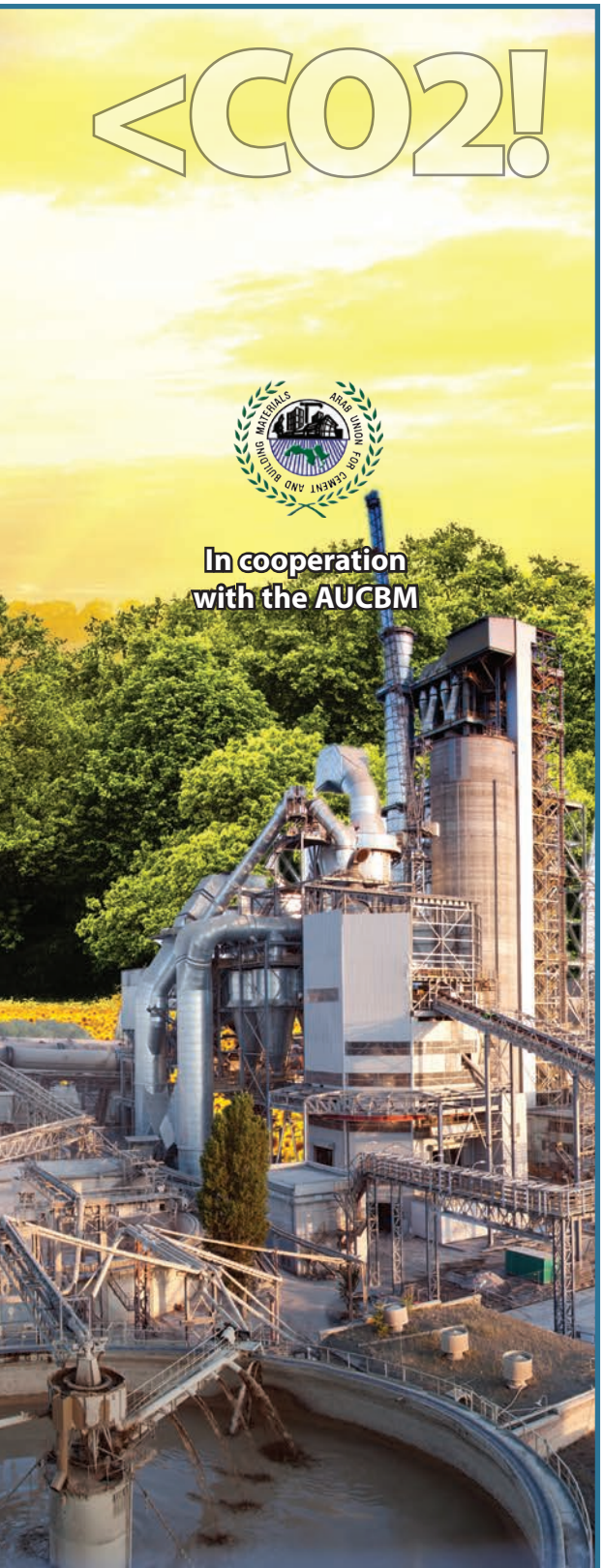


Confirmed presentations:

- 'Low carbon technology roadmap for the global cement sector,' Araceli Fernandez, International Energy Agency
- 'The role of the Global Cement and Concrete Association in promoting future industrial sustainability,' speaker to be confirmed, GCCA
- 'HeidelbergCement's strategy and implementation examples to stay in line with Paris-agreements,' Jan Theulen, HeidelbergCement
- 'Envisioning a carbon-negative roadmap for Dalmia Cement,' Ashwani Pahuja, CSO, Dalmia Cement
- 'Implementation of the EU ETS,' (TBC) Ms Mette Koefoed Quinn, Head of ETS Implementation and IT Unit of the Director General for Climate Action (DG CLIMA), European Commission
- 'Carbon emission cost implications for the cement industry in a decarbonising Europe,' Trevor Sikorski, Energy Aspects
- 'The methodology and potential impact of carbon pricing in the construction value chain,' Michel Folliet, IFC Global Manufacturing
- 'Fossil/biogenic content of cement industry fuels,' Haley Gershon, Beta Analytic
- 'Carbonate cements,' Fred Glasser, University of Aberdeen
- 'New clinker and cement production schemes,' Albrecht Wolter, Technical University of Clausthal
- 'Ecoefficient cement: realistic options for reducing the environmental impact of cementitious materials,' Karen Scrivener, EPFL, Ecole Polytechnique Fédérale de Lausanne
- 'European cement industry - current status and future trends,' (TBC), Koen Coppenholle - Cembureau
- 'Futurecem - A low-CO2 cement, tested at full-scale in the Danish Green Concrete II Project,' Jesper Sand Damtoft, Cementir Holding S.p.A.
- 'LC3 technology,' Karen Scrivener, EPFL Ecole Polytechnique Fédérale de Lausanne; Anne Dekeukelaere, Cementis
- 'Low CO2 cements by partial replacement with calcined clays or glasses - insights from solid-state NMR,' Jørgen Skibsted, Aarhus University Interdisciplinary Nanoscience Center (iNANO)
- 'Reduction of CO2 through optimisation of cement packaging,' Guido Neu, Haver & Boecker
- 'The cement industry's approach towards carbon capture,' Martin Schneider, European Cement Research Academy
- 'The LEILAC project: Demonstrating a novel carbon capture process,' Daniel Rennie, Calix Ltd

'No-fuel cement production using renewable-energy plasma technology and co-production of optimised process emissions for CCS/CCU: Results of comprehensive pre-feasibility study in Sweden,' Bodil Wilhelmsson, Cementa AB

- 'All cements are not the same: Selecting the right binders for future concretes,' John Blackstock, banah UK Ltd
- 'Cement plant CO2 capture for downstream utilisation in ready mixed concrete production,' Sean Monkman, CarbonCure Technologies
- 'Durable Aluminium Reinforced Environmentally-friendly Concrete Construction - DARE2C,' Harald Justnes, SINTEF Building and Infrastructure

Robert McCaffrey, Global Cement Magazine

The global cement industry in 2050

Some things never change, but in the years to 2050, we can expect profound shifts in societies, demographics, technologies, business and the environment. All of these factors will have huge effects on the cement and concrete industries. Using data from a wide variety of sources, here I give some suggestions on how the global cement industry will look in 2050.

The global cement industry will respond over the next three decades to some of the most momentous shifts in humankind's history. Populations will have increased from 6bn in 2000 to 9.7bn in 2050, while global urbanisation rates will increase from 47% in 2000 to around 66% by mid-century. Global GDP was US$33tn in 2000 but will have grown to nearly US$140tn by 2050. The world is rapidly ageing: 7% of the world's population was 65 or older in 2000 (420m people), but in 2050 it will be 17% (1.6bn people).

These statistics offer the global cement industry some of the greatest opportunities in its history. At the same time, the industry faces great challenges: it uses expensive energy to create a product with high emissions of CO_2, in an increasingly carbon-constrained world; it makes its product in highly capital-intensive factories in a sector with chronic over-capacity and decreasing barriers to entry.

I suggest in this article that the global cement industry will evolve into a more global, integrated, energy-optimised, lower- or no-carbon, increasingly automated business over the next three decades and beyond.

The unchanging future

Some important things will not change between now and 2050.

Human nature in all its forms will not significantly change: To a greater or lesser extent, we will all show greed, fear, laziness, ambition, ignorance, learning, kindness and many other attributes that go to make up human nature. However, figures suggest that we as a species are becoming less violent and that wars are becoming less prevalent.

Balance sheets and business will not change: It's never 'different this time.' Successful businesses will get three things right: They'll make things that people want to buy; they'll bring in more than they spend; They'll have money to spend when they need it. A loss will always be a loss and a profit a profit. No business can afford to make a continuing loss.

Markets will always be imperfect. Some things will be expensive, some things cheap. Some things will offer good value for money, and some things will not. Think of an iPhone or a tonne of concrete. Which offers the best value for money?

- Basic physics and chemistry will not change.
- Maths will not change.
- Our physiology will not change.

People will still eat and sleep, they will digest (and the rest) and they will procreate. They will be born, grow up and will age. They will move from place to place. Some will get ill and some will get better. However, we will all die, eventually. These things will not change.

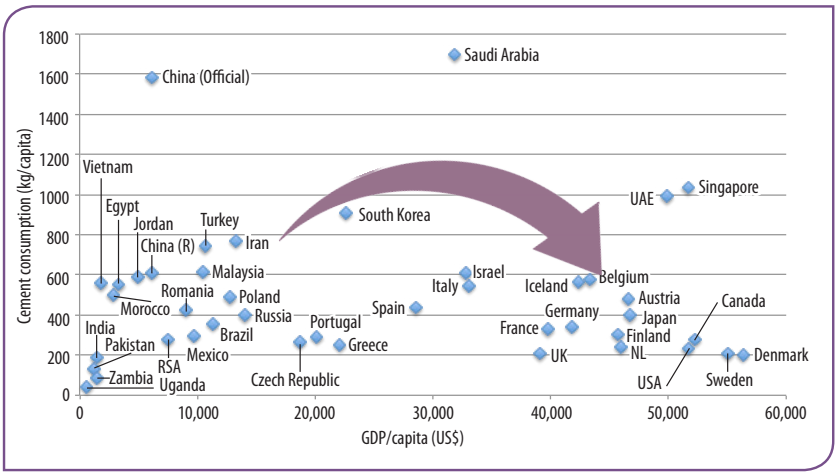
Below - Figure 1: A modern cement plant: Carthage Cement, Tunisia. **Source:** Amine Abdelkhalek, entrant to the *Global Cement Photography Competition*.

All of these unchanging things have had and will continue to have a profound effect on the cement industry. Human nature will still drive people to live in safe and comfortable surroundings, and to provide security and a healthy environment for their children. Cement and concrete can help. Human nature will drive people to innovate and so technology, including for the production of cement, will continue to become more efficient.

Concrete provides a value-for-money solution to a number of different problems that boil down to a need for immediate and then long-lasting bulk compressive strength. People are prepared to pay for that solution, especially since it offers better value-for-money than currently available substitutes. Cement companies can supply cement, the basic ingredient of concrete, at a profit, and so they do.

People need/want hospitals, schools, roads, houses, railways, energy (production/transmission), bridges, shops, offices and working areas, sewage and waste-water treatment facilities, and other infrastructure, and they always will. Concrete is a suitable material for building large proportions of these facilities. These things wear out eventually, and have to be replaced or renovated. Whether for building or replacement, concrete will be used.

Peak per-capita cement consumption comes as countries transition from rural to urban societies, and as urban infrastructure is progressively built (Figure 2). As countries modernise and urbanise, their cement consumption has historically increased from around 100kg/capita in rural populations, to a peak of around 1500kg/capita/yr, before slipping back to the long term average for developed countries that sporadically build new infrastructure but mostly just renovate, of around 500kg/capita/yr. There is no strong reason to believe that this historical and global trend will change. This evolution from undeveloped/rural nation through developing nation to developed nation status is happening worldwide, and gives a strong pointer for future concrete consumption.



Above - Figure 2: Development of per capita cement demand (kg/capita) with increasing wealth (GDP in US$/capita).

However, clinker ≠ cement ≠ concrete.

Future changes

It is difficult to make predictions, especially about the future. After all, although there is but one present, there are infinite possible futures (Figure 3). However, we can be sure of the boundary conditions of the future since some changes are already either unavoidable, or already underway:

- Demographic changes;
- Environmental changes;
- Economic and societal changes;
- Technological changes.

Demographic change

On the day I was born, in June 1967, there were 3,362,920,394 people on the planet. Today there are twice as many, 7.7bn, increasing by 82m per year. In the coming decades, Asia (including India and China) and Africa will grow dramatically in population numbers. Together, they had 4.55bn people in 2000 (820m in Africa), they have 5.9bn in 2019 (1.32bn in Africa) and by 2050 they will have a combined population of 7.78bn people, of which 2.5bn will be in Africa. The population of the USA will grow from 282m in 2000, to 330m in 2019 and perhaps to over 400m in 2050.

The 10 most populous countries in 2050 will be India, China, the US, Nigeria, Indonesia, Pakistan, Brazil, Ethiopia, Bangladesh and the Philippines. In other countries, the population will be static or falling, particularly in Eastern Europe, Russia, South Korea and Japan. Starting in around 2030, China's population will start to fall, and it will probably lose around 50m people between 2030 and 2050.

At the same time, many countries in the world will have an ageing population, most notably Japan, Spain, Portugal, Greece and Korea, where nearly 40% of the population will be aged over 65 years by 2050: Over 25% of China's population will be over 65 by the same time.

It has been said that if the 1900s were the American Century, then the 2000s will be the Chinese Century. However, by 2050, China will be in relative decline. It may turn out that the 2050s and beyond will be the African semi-century.

Environmental change

It is undeniable that the Earth's atmosphere has warmed, and this has led to many recent years being the hottest on record. Due to the amount of CO_2 that we have already put into the atmosphere, the world will continue to heat up, with a variety of environmental impacts. That will be bad enough, but possibly worse is the widespread degradation and destruction of wildlife habitats, reduction in biodiversity and of the pollution and over-exploitation of the seas. Climate change will affect increasing numbers of people around the world.

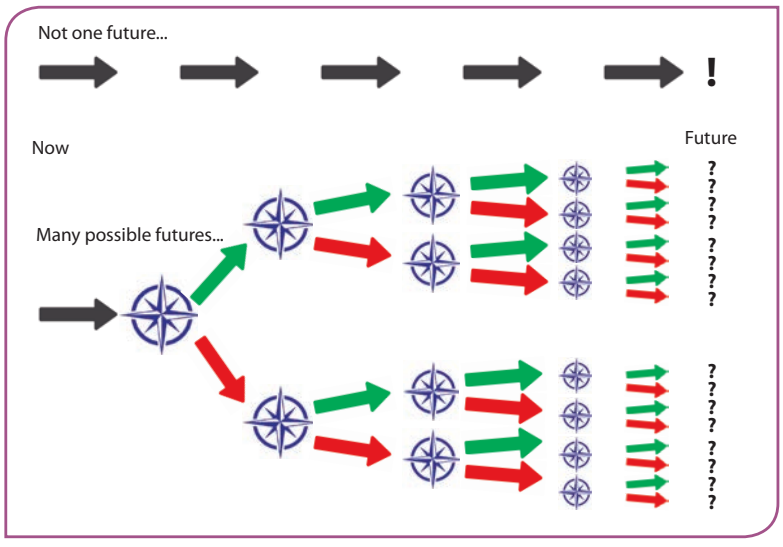
Due to political action, the price of emitting carbon/carbon dioxide in Europe has increased, from practically zero in 2000 to Euro/US$25/t in 2019 and probably to beyond Euro/US$50/t in 2050.

Economic and societal change

Major changes in human society are inevitable. Globalisation will continue, but China will lose some of its economic advantages as its population drops and wage inflation increases. Manufacturing may shift to Africa, to take advantage of lower wages. Global income inequality will continue but extreme poverty will decrease. Gender inequality will decrease worldwide, particularly as women continue to enter the workforce.

At the same time, literacy will increase, hand-in-hand with a global increase in urbanisation (which will grow from 47% in 2000, to 55% in 2019, and to 66% in 2050). Between now and 2050, we will probably see at least one, if not two, major recessions (possibly originating in China).

Below - Figure 3: There are infinite possibilities for the future - depending on our decisions and choices from now onwards (cf Brexit). Diagram after Lloyd Walker.



Technological change

Here are just some of the technological changes that are forecast to affect the world over the next few decades:

- Commercial fusion power;
- Continued growth of renewable energy;
- Efficient, low-cost energy storage technologies;
- General artificial intelligence;
- Self-driving cars;
- Cures for HIV, malaria, Alzheimer's, meningitis and cancer;
- Global internet usage of >90%;
- Immersive virtual reality;
- Humanoid autonomous robots explore Mars...

... but there will be other technological developments that we just don't see coming.

Cement industry technology change

Specifically in the cement industry, we are seeing a maturity in technology that makes it harder to achieve significant gains in energy efficiency with improved machinery.

- Vertical roller mills, horizontal roller mills and roller grinding presses have brought high levels of grinding efficiency (in terms of specific energy consumption) to raw meal milling and clinker grinding;
- Improved designs of separators, cyclones, fans and burners are moving process gases ever-more efficiently;
- Multi-stage, multi-string, preheater, precalciner pyro-systems with efficient coolers and waste heat recovery are reducing energy consumption towards the theoretical minimum heat input for clinkerisation (best available technique (BAT) levels for new plants and major upgrades are 2.9-3.3GJ/t clinker, compared to the theoretical minimum of 1.6–1.85GJ/t clinker). Practical and cost considerations mean that efficiency is nearing a plateau;
- Clinker grindability factors are better understood and are being optimised to reduce grinding energy requirements;
- Increased automation and digitalisation in factory operation (including improved sensor strategies, remote diagnostics, big data analysis (including AI-analysis of unstructured data such as images and video), virtual equipment and plants, computed strength development, widespread in-house use of CFD and intelligent control systems (based first on 'knowledge capture' and then on machine learning) will lead to stabilised and optimised systems and further efficiency gains in clinker production;
- The emphasis on 'digitalised' cement production (with some plants now being operated remotely and by AI) will mean that cement plants will be increasingly sensitive to digital disruption: worms, trojans, viruses and malicious hackers are potentially company-destroying problems. Cyber security will become a critical priority for cement plants in the future;

• Where expensive and fallible workers can be replaced by automation, they will be;

• There will be an increased emphasis on 'high tech' clinker production, with progress perhaps directed by information engineers, working with mechanical, chemical and electrical engineers.

• High-tech cement will use a variety of today's emerging technologies:

- Solar or electric heating;
- Indirect firing with carbon capture;
- 100% use of zero-CO_2 (biomass-based) alternative fuels;
- Lowest-possible CO_2-emitting raw/recycled materials;
- Optimised clinker grindability for lowest specific grinding energy;
- Ultra-high-strength clinker/cements.

The end-point will be an autonomous factory that produces the exact amount and type of cementitious binder, with lowest possible CO_2 emissions, upon a remote command, without human intervention - a kind of 'Autocem plant.'

Cement sector changes to 2050

Technological changes in the cement industry (production efficiency, automation) will continue, as outlined above. However, it is at the intersection of demographic, environmental, economic, societal and technological changes that the cement sector will see the most change in the years to 2050;

• Capital costs for new production capacity have dropped due to the entry of Chinese engineering companies into international markets: Barriers to entry for potential new cement producers are now lower than ever;

• There is currently a global overcapacity crisis - with too much clinker chasing too few buyers and widespread uneconomic low production capacity utilisation (Figure 4);

• Some of this overcapacity may be taken up through demand growth (for example in Africa), but companies have an ongoing tendency to build too much capacity in order to protect market share.

• Countries that are suggested to transit from developing to developed status by 2050 include: Argentina, Chile, China, Costa Rica, Croatia, Hungary, Iran, Kazakhstan, Latvia, Lithuania, Malaysia, Panama, Poland, Romania, Russia, Saudi Arabia, South Africa, Thailand, Turkey, UAE, Uruguay;

• As more and more countries become mature, they will morph into 'renovation mode' - and their cement demand will drop by 30-60%;

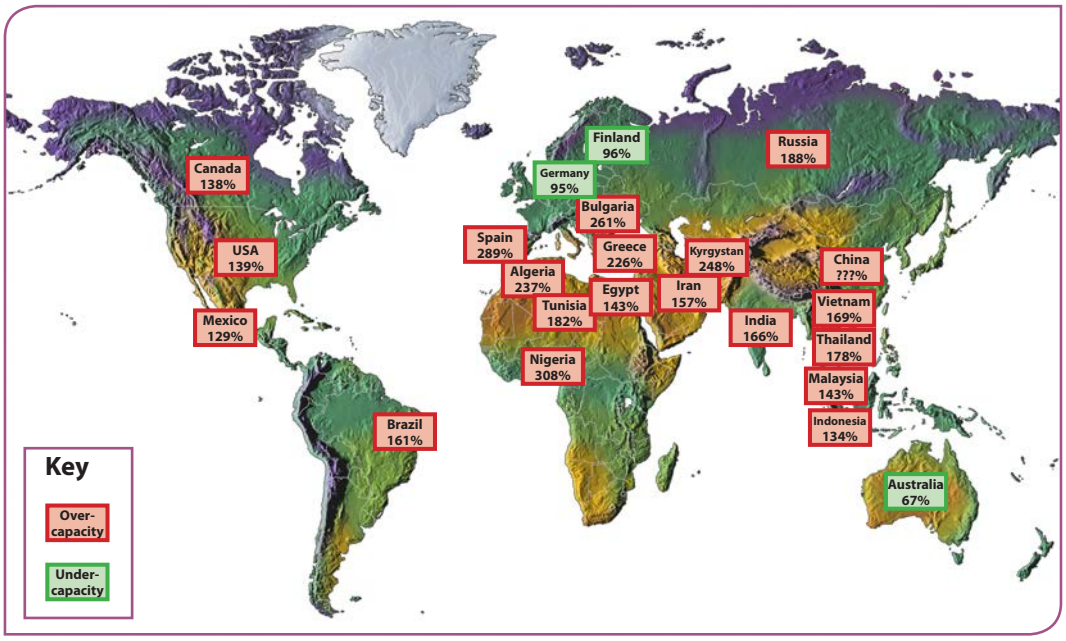
• There are far too many 'legacy' cement plants. Too many are too small, too polluting, too inefficient: In an ongoing trend, they will be closed (or turned into grinding plants and/or distribution terminals);

• Cement companies got 'burned' in the financial crisis, finding themselves with too much debt: They are in a decades-long process of 'deleveraging' (paying back debt). For example, LafargeHolcim aims to pay down its debt to achieve two times or less 'Net Debt to Recurring EBITDA ratio' by the end of 2019. During deleveraging, less money is available for capital projects, jobs and maintenance;

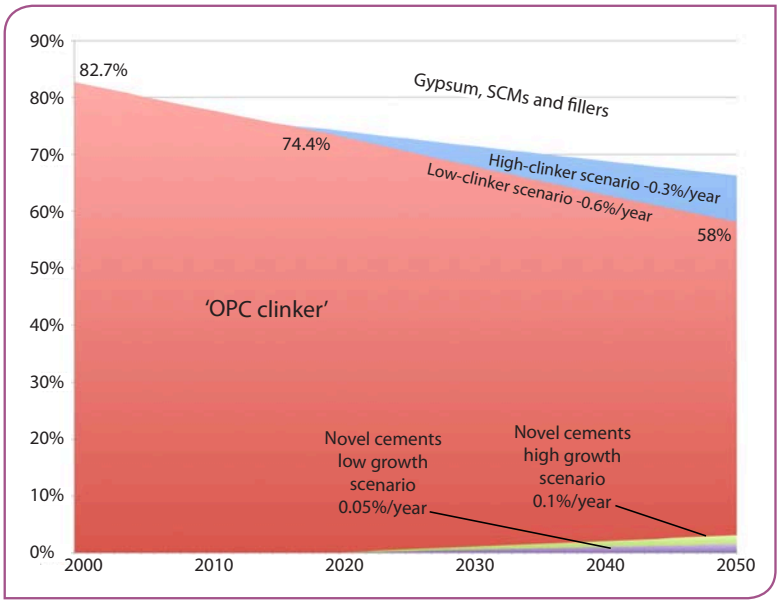
• New 'greenfield' cement plants are essentially now 'off the menu;'

• Fast-payback projects such as using alternative fuels and the use of waste heat recovery for electricity generation will become even more widespread;

• Legacy clinker production will be concentrated into large, modern, efficient and relatively non-polluting 'mega-factories,' ideally with good transportation connections (a good example being



Right - Figure 4: Global cement market overcapacity: Cement production capacity expressed as a percentage of each country's cement demand in 2018. Figures from *Global Cement Directory 2019.*



Above - Figure 5: Global clinker factor trends, 2000-2050. The high-clinker scenario sees the clinker factor decreasing by 0.3% per year, whereas the low-clinker scenario sees its current trend of a reduction of 0.6% per year continuing. Novel cement growth scenarios range from 0.05% market share growth per year to 0.1% market share growth per year.

the 12,000t/day LafargeHolcim Ste Genevieve plant on the Mississippi River) - See Page 74).

• New high-tech cement plants may be built for low- or zero-CO_2 production;

• Cement plants may find themselves under physical or cyber attack by environmental activists in the future;

• Our studies show that ownership in the global concrete industry is extremely fragmented and is ripe for rationalisation. LafargeHolcim under new CEO Jan Jenisch is busy selling non-performing cement assets in over-supplied countries and reinvesting in concrete companies;

• Vertical integration (cement-aggregates-concrete) will continue: There is more synergy (profit) to be gained from optimising the cement-concrete business than from just efficiency gains from the cement industry alone;

• Given the rapidly escalating cost of carbon emissions, expensive and polluting clinker production will become less profitable;

• Cheaper low- or no-CO_2 substitutes for clinker will increasingly be used (including novel cements, fillers, blends etc) (See Figure 5);

• Iron and steel slag and coal-fired power-station flyash have their own associated CO_2 emissions, so that with increased demand (for use in low-clinker-factor cement) and reduced supply (due to the rise of Electric Arc Furnaces and the progressive demise of coal-fired power stations), slag and flyash costs will dramatically increase.

• The increasing cost of clinker will strongly spur the cement-concrete industry towards innovation in mix design and use.

• Cement-concrete companies will become 'mix-agnostic' - not favouring clinker over other functional ingredients - as the clinker production part of their business becomes less profitable.

• Development of additives and ultra-fine cement grinding may result in reduction of the cement content of concrete;

• There will continue to be innovation in the properties of clinker/cement-based concrete, including:

- Self-diagnosing concrete;
- Self-repairing concrete;
- Carbon-storing concrete (eg: Solidia);
- Thermal insulating concrete;
- Heat-conducting concrete;
- Permeable concrete;
- Lightweight concrete;
- Light-transmitting concrete;
- Translucent concrete;
- Light-emitting concrete;
- Electricity-storing concrete;
- Ultra-high strength concrete (>100MPa);
- Glass-fibre reinforced concrete.

• There will be a clearer focus on lifetime emissions from buildings: Although clinker may be CO_2-intensive, low-clinker cement, and low-cement concrete is less-so. Due to thermal inertia, building durability and 'insulatability,' concrete may still be chosen over alternative materials (such as wood, steel, glass and plasterboard). We await the figures to prove that buildings based on concrete have lower lifetime emissions compared to other building materials.

• Alternatives to traditional cement and concrete will continue to be developed, including alkali-activated cementitious material (AACM) (using a high percentage of GGBS, e.g. Cemfree); geopolymer cements (alkali-activated metakaolin, e.g. banah UK); geopolymer/concrete hybrids (e.g. C-Probe);

• Concrete will continue to compete in an intense struggle for market share with its potential substitutes in a range of applications, including asphalt, plasterboard, bricks, timber, steel, glass, aluminium and others.

• Concrete will continue to be used when it is the cheapest suitable material: Other materials will be used when they are the cheapest suitable material.

Caveats

All of the future-looking statements in this article presuppose that nothing untoward occurs in the years to 2050 that affects regional or national economies, apart from the previously-mentioned likely global or regional recessions and environmental degradation.

However, other more-or-less likely events that could affect widespread economic development might include: global insect population collapse ('insectageddon'); Cascadian and other 'Ring of Fire' earthquakes and tsunamis; long-term trade wars; Chinese regime change; US debt default; economic and/or political collapse of the EU; pandemics; a crisis in antibiotic resistance; the global sand crisis (etc) (See Figure 6).

Conclusions

Cement-based concrete has been providing building solutions for more than 2000 years. The raw materials to make concrete are widely available. It is cheap, durable, strong and fairly easily installed by semi-skilled labour. Huge installed bases of cement manufacturing facilities, aggregate quarrying and concrete production give the clinker-cement-concrete industrial complex an almost unstoppable momentum. However, even the largest supertanker can be turned with enough time.

If the companies that currently make clinker and cement, and which will increasingly make the concrete, decide that there is profit - or more profit - from making low- or no-CO_2 cements and low-cement concrete, then they will be likely to invest in these higher-margin business lines.

The following final predictions should be treated with caution:

- Global population will be 9.8bn in 2050, compared with 6bn in 2000 and 7.76bn in 2019;
- The world will rapidly be ageing;
- Economic development will have shifted from west to east – but Africa will also be growing, fast;
- We will have had at least another two major recessions/bubbles/financial meltdowns by 2050;
- Carbon emissions will become expensive and will be important for all calculations and decisions;
- Carbon-neutral fuels will be ubiquitous;
- Waste heat recovery units will have moved beyond Japan, India and China and will be widespread throughout the rest of the global cement industry;
- We will still make Portland clinker, but in more sophisticated and efficient ways: Novel cements will take market share from 'traditional cements';
- The number of cement plants in developed countries will halve by 2050 compared to 2000;
- Cement plant operation will be progressively automated: expect widespread levels down to 100workers/Mt of production;
- The *clinker* intensity of construction will decrease, due to the use of lower-CO_2 cements, but the *concrete* intensity of all construction will have increased due to urbanisation;
- Cement companies will be increasingly vertically integrated (cement-aggregates-concrete);
- Global clinker overcapacity will continue;
- Grinding plants will become more common;
- The price of cement will have to increase in real terms, to reflect its increased costs.

For more information please see www.Cement2050.com

Below - Figure 6: 'Disastergram/Opportunitygram,' showing all future scenarios according to their likelihood and magnitude of possible effects. Axes not to scale and opinions are the author's own.