Future Cement Initiative: Saudi Arabia's bold vision

Giga-projects continue to drive Saudi Arabia's cement demand at a time when the country targets carbon neutrality by 2060. The recent Future Cement Initiative workshop at King Abdullah University of Science and Technology showed that the cement industry is pursuing multiple pathways to achieve this goal.

■ by ***Prof Bassam Dally***, *Future Cement Initiative, Saudi Arabia*

Saudi Arabia has prioritised decarbonisation of the country's cement industry within its national development goals. Through the Saudi Green Initiative (SGI), the kingdom has committed to decrease national CO_2 emissions by 278Mta by 2030 and achieve net-zero emissions by 2060. These targets are particularly significant for the cement industry, which supports Vision 2030's unprecedented construction plan despite being among the most carbon-intensive industries worldwide.

Figure 1: drone photograph of a quarry in kaolinitic sandstones near Al-Jawf

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Facing the dual challenge with deployable technical pathways

Saudi Arabia's cement demand is projected to grow significantly over the coming decade, driven by giga-projects such as NEOM, Red Sea Project, FIFA World Cup 2034 stadia and other infrastructure development projects. With current demand estimated at 49Mta and projections indicating demand will approach 70-75Mt by 2030, the sector faces a dual challenge: enabling national development while sharply reducing its carbon footprint. This policy backdrop has created an urgent need for scientifically grounded, locally relevant and industrially deployable solutions.

Against this backdrop, more than 200 industry leaders, researchers and policymakers gathered at King Abdullah University of Science and Technology (KAUST) on 8-9 December 2025 for the Future Cement Initiative (FCI) workshop.

FCI was officially launched by Minister for Industries and Mineral Resources, HE Bandar Al-Khorayef, in January 2025. It has been established as a platform to connect fundamental research with industrial deployment, focussing on practical decarbonisation levers that can be implemented within Saudi Arabia's specific operating conditions.

The workshop at KAUST was designed not as a conventional conference but as a working forum to align national policy ambitions with deployable technical pathways grounded in research and industrial practice.

Opening the workshop, Deputy Vice Minister for Mining Development at the Ministry of Industry and Mineral Resources, HE Eng Turki Al-Babtain, pointed out the strategic value of the cement sector and the scale of transformation needed. He emphasised that Saudi Arabia's development goals must now be delivered alongside deep emissions reductions, noting that innovation, efficiency and collaboration between government, industry and academia will be essential to achieving this transition.

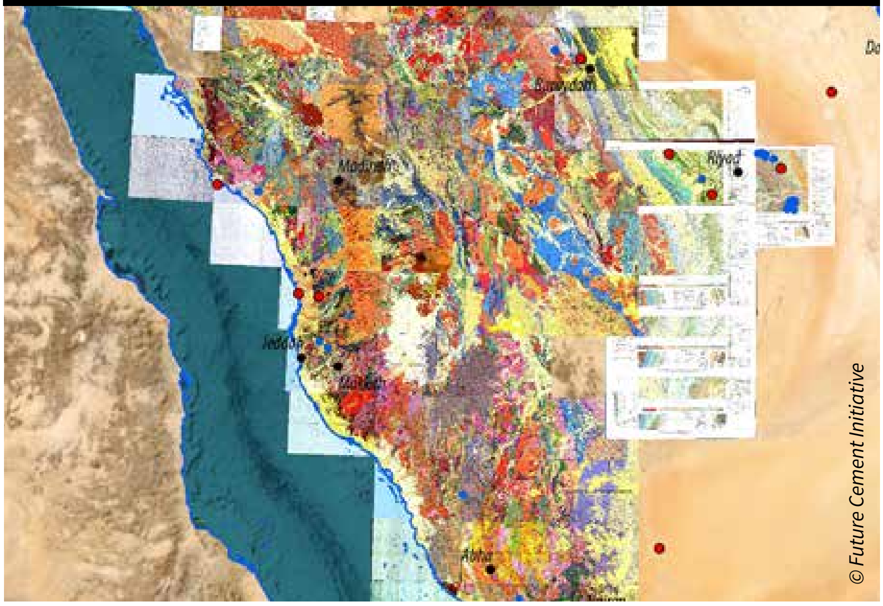
Dr Badr Johar, chair of the National Committee for Cement Companies, highlighted cement's historical contribution to Saudi Arabia's development and its prospective role in achieving Vision 2030. The sector is presently at a pivotal crossroads, with decarbonisation, new materials, digitalisation and operational efficiency progressively shaping its competitiveness.

At the core of the workshop was FCI's scientific work at KAUST, chaired by Prof Bassam Dally. Prof Dally outlined FCI's guiding principle: cement will remain indispensable to the kingdom's development, but the emissions associated with its production must be mitigated through evidence-based innovation. He stressed that FCI's role is to develop and validate technologies, train industry professionals and support policy-aligned deployment pathways that enhance both environmental performance and global competitiveness.

Alternative fuel usage

One of the most important opportunities addressed at the workshop was the replacement of fossil fuels in cement kilns with waste-derived alternative fuels. Scientific and technical sessions examined how Saudi Arabia's municipal solid waste (MSW) streams could be processed into refuse-derived fuel (RDF) suitable for cement kiln co-processing, reducing reliance on heavy fuel oil while supporting national waste-diversion objectives. Saudi Arabia produces ~20Mta of MSW.

Figure 2: Geological maps (1:250,000) by the Saudi Geological Survey. Red dots represent cement plants and blue dots are location of surveyed sites



The workshop indicated that ~40 per cent (7.8Mta) can be converted into alternative fuels, potentially reducing heavy fuel oil consumption by 18Mbbla. If Saudi Arabia sells recovered oil at global market prices instead of subsidised rates (assuming only a US$30/bbl difference) this could generate ~US$54m annually, sufficient to establish a comprehensive sustainable waste management system.

The first day of the workshop was dedicated to an industry course, delivered by personnel from MVW Lechtenberg & Partner, addressing the use of RDF in cement kilns focussing on opportunities and challenges for Saudi Arabia operators.

National waste management and alternative fuel initiatives presented by Eng Sultan Alsaif of TerraFuel and Eng Sami Alrashdi of the National Center for Waste Management (MWAN) illustrated how emerging infrastructure and regulatory frameworks can enable the decarbonisation of the cement sector at scale.

The session highlighted that the climatic advantages of RDF are contingent upon lifecycle performance, encompassing the biogenic component of waste, logistics and comprehensive emissions monitoring. Alternative fuels were identified as a viable, immediate solution for achieving significant emissions reductions while more advanced technologies develop over time.

Carbon reduction, clinker substitution and new materials

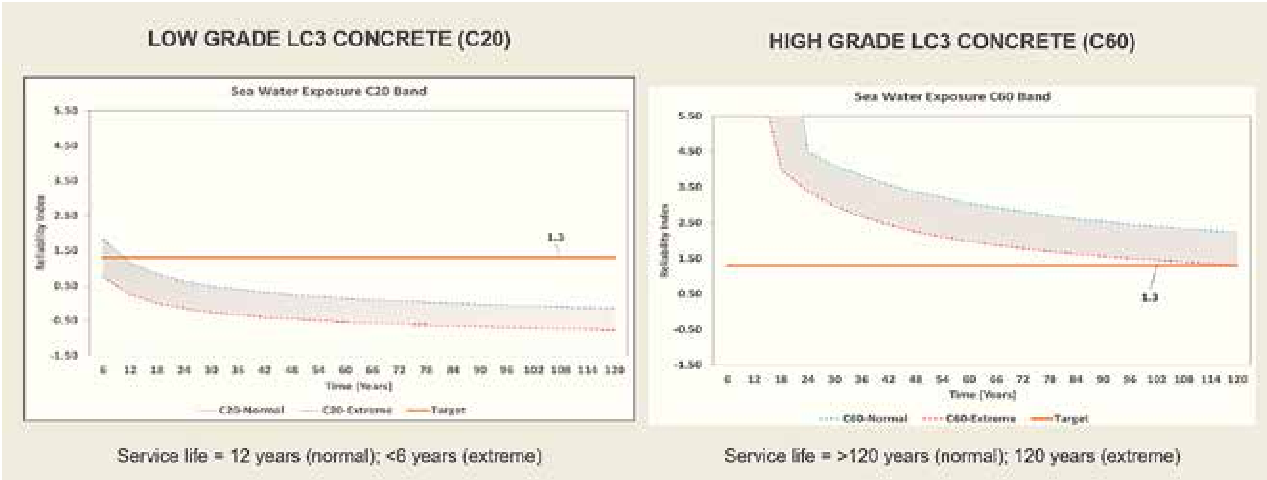
From January to December 2025, FCI started multiple significant research initiatives focussed on clinker substitution, carbon reduction and the development of new materials. FCI created a website (fci-sa.org) and actively collaborated with prominent Saudi organisations, such as MWAN, SASO (Saudi Standards, Metrology and Quality Organization) and SBC (Saudi Building Code).

Mitigating process emissions from limestone calcination is essential for attaining profound decarbonisation. Prof Mani Sarathy of KAUST's Clean Energy Research Platform presented research on carbon capture and utilisation (CCU) pathways relevant to cement plants, including the transformation of captured CO_2 into fuels and chemicals, such as methanol, when paired with low-carbon hydrogen. The presentation emphasised Saudi Arabia's robust solar resources as a facilitator for green hydrogen production. The country endures high solar radiation throughout most of the year, typically exceeding 6kWh/m^2/day in some areas, markedly surpassing global norms. This inherent advantage uniquely positions the country for the generation of solar-powered green hydrogen in conjunction with carbon capture. Oxyfuel combustion has become the most economically viable method for CO_2 capture, with anticipated costs of between US$70m-90m for a brownfield testing facility that processes 500tpd.

A further key pillar of FCI's approach for a sustainable cement industry in Saudi Arabia is the reduction of clinker content through supplementary cementitious materials (SCMs) and innovative cement formulations. Prof Abdulkader Afifi (KAUST) presented findings from the KaoCem programme, which has conducted an extensive national survey of Saudi clay deposits to assess their suitability for calcined clay applications. During 2025, field campaigns covered more than 11,000km across different regions in Saudi Arabia and visited 65 sites of particular interest (see Figures 1 and 2). The team gathered numerous samples, totalling around 300kg of raw material from areas such as Hail, Yamamah, Yanbu, Najran, and Al-Jawf. Laboratory analyses using X-ray diffraction (XRD) confirmed that nearly all the samples analysed contained kaolinite, though in varying proportions. The research team categorised the materials according to their mineralogical composition. Type 1 clays had a kaolinite-dominant composition with negligible presence of other clay minerals, whereas Type 2 clays comprised kaolinite-rich material with minor indications of illite or illite-smectite. This research showed that the Hail/Zabirah and Yamamah regions are notable for their high-purity kaolinite resources. In certain regions, the kaolinite-to-quartz peak ratios exceeded 13 and, in certain extreme instances, surpassed 30, signifying outstanding potential for calcination into highly reactive metakaolin. The study illustrates that locally sourced kaolinitic clays can be thermally activated at temperatures between 600-800°C and utilised to substitute a significant portion of clinker, hence facilitating production of formulations such as limestone calcined clay cement (LC^3) with clinker replacement rates of 15-40 per cent. The research demonstrated that lower-grade clays with minor kaolinite content, when coupled with quartz or feldspar, can effectively function in LC^3 cement blends, as their filler effects and partial reactivity help reduce clinker requirements. This dual-track system broadens the spectrum of available resources, guaranteeing supply security and adaptability for the industry.

Complementary research led by Prof Hussein Hoteit investigated the CO_2 sequestration potential of Saudi cement-based materials. The project, which began in March 2025, examines both conventional binders and experimental blends incorporating basaltic pozzolan as an SCM. Different mortar groups were prepared using ordinary Portland cement, Portland cement with natural pozzolan and basaltic blends. Phenolphthalein

Figure 3: service life modelling, sea water exposure – NEOM



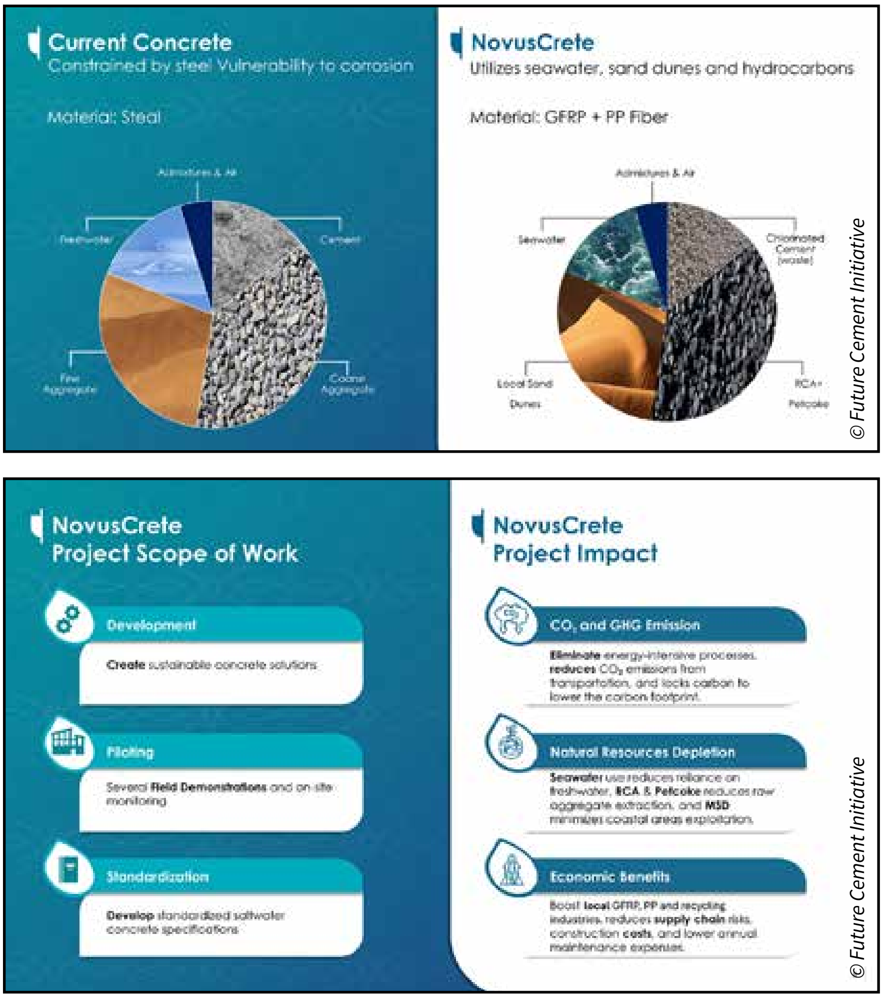
testing demonstrated that after only three months of outdoor exposure, even dense ordinary Portland cement mortars showed a measurable carbonation depth of a few millimetres, while several more porous systems exhibited near-complete carbonation. Indoor (21°C) and outdoor (>35°C) exposures highlighted the significant acceleration of carbonation under the climatic conditions of Saudi Arabia. This research confirms that due to the region's warm climate and humidity patterns, Saudi concrete may take up CO_2 from the atmosphere at a faster rate than in many other parts of the world. Custom CO_2 drawdown chambers with high-precision probes were used to quantify CO_2 uptake over time. Tests demonstrated that absorption rates corresponded with pore structure, with all binders exhibiting less uptake at older ages, in accordance with the decelerating characteristics of carbonation.

In conjunction with this research, Eng Hussam Nasreddin (NEOM) introduced concepts for ultra-high-performance concrete aimed at long-lasting infrastructure, attaining exceptional compressive strength while markedly decreasing clinker content. Such approaches provide significant savings in whole-life carbon by prolonging service life and minimising material intensity (see Figure 3).

Innovative concrete formulas tailored to the environmental restrictions of Saudi Arabia were also examined. Eng Abdullah Alqahtani presented research on seawater-based concrete systems (NovusCrete) aimed at minimising freshwater usage – crucial for water-scarce Saudi Arabia – and decreasing dependence on virgin aggregates, a significant factor in dry regions with ongoing construction demands (see FIgure 4). The Novus Crete demonstrated the first pilot at NEOM Innovation Hub and achieved >60MPa strength.

Dr Sara Alkhalaf presented research on ultra-high molecular weight polyethylene (UHMWPE) additives to improve cement performance (see Figures 5 and 6). The FCI project, supervised by Prof Sanjay Rastogi, commenced in April 2025 and aims to develop functionalised UHMWPE derivatives that can be used with cement to improve compressive strength by a minimum of 50 per cent. The research team successfully synthesised many

Figure 4: seawater-based concrete systems are aimed at minimising freshwater usage, key in areas of water scarcity



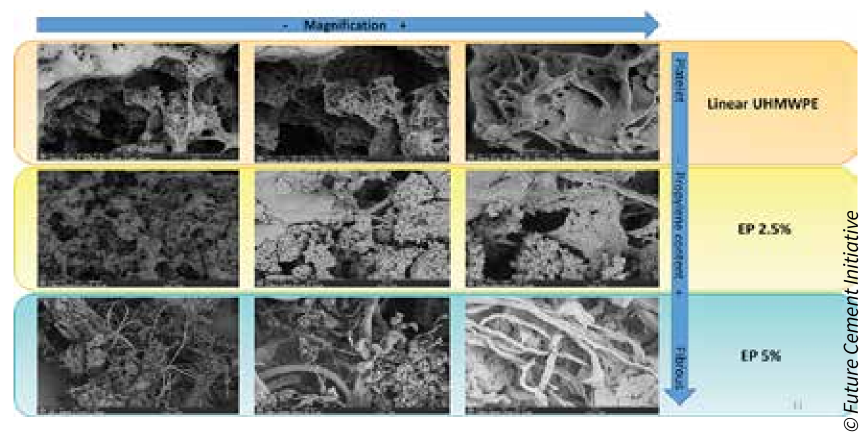


Figure 5: SEM result for UHMWPE and ethylene propylene random copolymers – KAUST

Figure 6: thickening time test for UHMWPE with cement – KAUST

functionalised ultra-high molecular weight polymers. Measurements of the water contact angle indicated that these materials demonstrated enhanced hydrophilicity, with contact angles decreasing from 137 to 84.5°, signifying increased compatibility with cement matrices.

A concurrent initiative focussed on high-performance graphene-infused low-carbon cement composites, led by Prof Bassam Dally and Prof Husam Al Shareef, began in June 2025. The research seeks to examine graphene's ability to mitigate strength reductions commonly associated with elevated clinker replacement levels.

Innovative construction

The workshop also addressed innovative construction technologies beyond conventional cement and concrete. Eng Vasim Barkavi presented progress on large-scale 3D concrete printing, demonstrating rapid construction rates, reduced labour requirements and lower material waste. Plans include localising printer manufacturing and material formulations for Saudi climatic conditions. Dr Bandar Fadhel of Aramco presented patented approaches for sustainable 3D printing incorporating CO_2 injection during printing, demonstrating both CO_2 avoidance and uptake while achieving structural integrity under outdoor conditions (see Figure 7).

Furthermore, the workshop incorporated industry perspectives to provide context for deployment. Saudi Readymix, represented by Chris Leptokaridis, outlined its R&D-driven strategy for increasing SCM usage, reducing clinker intensity and integrating advanced materials across its product portfolio.

From policy to practice

The FCI workshop showed that a single technological solution cannot address Saudi Arabia's cement decarbonisation challenge. Instead, it requires a coordinated portfolio of measures: alternative fuels, clinker reduction, advanced materials, efficiency improvements, and, ultimately, carbon capture.

Between 2025 and 2027 Saudi Arabia must launch an intensive two-year programme that pairs aggressive technology roll-outs – including waste-derived fuel pilots, full conversion of kilns to natural gas, commercial LC^3 cement production, kaolinite beneficiation plants and waste-heat recovery to cut cement-sector emissions – with rapid policy upgrades, including performance-based building codes, mandatory Environmental Product Declarations, a green-cement certification and a carbon credit mechanism.

If implemented together, these steps can achieve the 27-30 per cent intensity reduction needed to keep the kingdom on track for its 2030 pledge and position Saudi cement as a regional low-carbon benchmark. ■

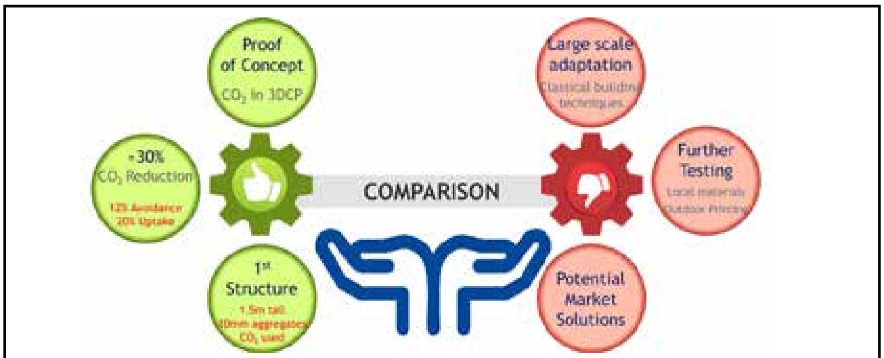


Figure 7: Aramco 3D Concrete Printing with large aggregates and CO_2 curing

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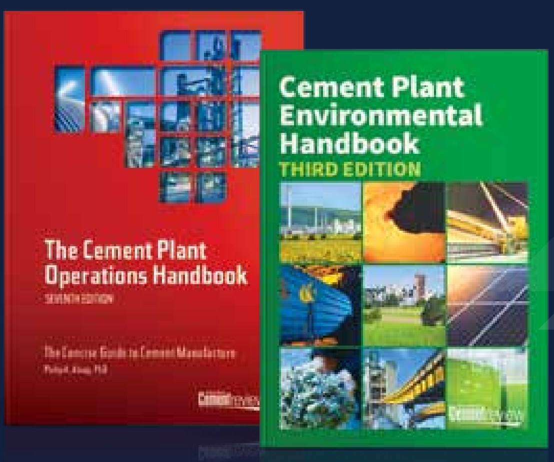

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