Cold-activated clay cement: a low-carbon breakthrough

As the cement industry faces rising costs and tightening decarbonisation pressures, traditional solutions based on calcined clays are proving increasingly complex and capital-intensive to scale. This article introduces Materrup's CCC® (Cold-activated Clay Cement) technology, an industrial breakthrough that activates clay at ambient temperature through a fully electric, kiln-free process. By combining low-carbon emissions, reduced costs and a decentralised production model, CCC offers a compelling new pathway for producing sustainable cement at scale.

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In a global context where supplementary cementitious materials (SCMs) such as ground granulated blastfurnace slag (GGBS) and fly ash are experiencing sharply rising delivered prices, the total cost of low-carbon binders has become a front-line concern.

Locally sourced clay-based SCMs represent a major economic alternative for cement decarbonisation. Calcined-clay routes, flash-calcined clays and limestone calcined clay cement (LC^3) binders have demonstrated significant clinker reduction potential. However, their industrial deployment often remains constrained by high capital expenditure, complex thermal integration, feedstock selectivity (kaolinite content) and elevated ancillary demand, all of which limit the scale-up of these solutions.

Rather than relying on a thermal process, Materrup employs a cold, fully electric route: its proprietary CCC® (Cold-activated Clay Cement) technology, invented in 2018 in France and protected by more than 100 international patents, activates clay at ambient temperature through a mechanochemical process – without a kiln, without calcination. At Saint-Geours-de-Maremne (France), this technology has been operating at industrial scale since 2022, supplying structural concrete applications with tens of thousands of cubic metres already poured. CCC offers a low-carbon pathway with low capital and operating expenditures, decentralised by design, located close to both raw material deposits and end markets, thereby greatly reducing the transport distances between material processing and use.

Figure 1: CCC® combines low-carbon emissions, reduced costs and a decentralised production model to produce sustainable cement at scale

CCC technology: invention and cold activation mechanisms

Materrup reinvents cement and clay activation by eliminating the thermal treatment step. CCC technology activates clay at ambient temperature through a mechanochemical process, without calcination. The clay is rendered reactive by combining controlled fine mechanochemical grinding with the action of an organic agent to form a hybrid organo-mineral material.

Mechanical activation places uncalcined clay minerals within the broad category of "natural pozzolanic materials" activated by physical means: controlled grinding transfers energy to the material, promotes delamination of layered structures, reduces particle size, and induces structural disorder and lattice defects, thereby increasing the effective reactive surface area. In an alkaline environment, these transformations facilitate the dissolution of Si and Al species, contributing to the pozzolanic reaction.

The introduction of an organic agent, at very low dosage, acts at particle interfaces to enhance surface reactivity and promote the formation of organo-mineral complexes, while limiting agglomeration.

This mechano-organic coupling maximises activation efficiency within an optimised processing window and imparts high reactivity to the clay without any thermal step. This process can be described as cold mechano-organic activation.

CCC industrial process architecture: a compact "3-in-1" module

In contrast to calcined clay process chains, the CCC-based cold activation process relies on a 100 per cent electric industrial architecture operated at ambient temperature and is significantly more compact.

After raw material reception and homogenisation, the core of the process consists of a single module integrating the three key functions – moisture control, activation and classification – followed by product storage and finishing. This

Table 1: flash calcination vs CCC — capex · energy · energy cost (Brent sensitivity) · CO_2/t of activated clay

Parameter	Flash calcination 750-850°C, gas	SMCP® 0.50Mta, ambient temp	SMCP 0.06Mta, ambient temp	Ratio flash/SMCP (0.50Mta/0.06Mta)
Capex – WACC 7%, 20-year amortisation				
Capex installed (EURm) [2-9]	23-70	14	3.5	–
Capacity (Mta)	0.100-0.400	0.500	0.060	–
Annualised capex (EUR/t) — WACC 7%	18.9-31.5	2.64	5.51	0.50Mta: 7-12x 0.06Mta: 3-6x
Energy/t of activated clay				
Thermal energy (kWh_{th}/t) [10-12]	523-698	0	0	–
Electrical energy (kWh_e/t) [1, 12]	18-23	25-60	40-80	–
Energy cost (EUR/t) · Electricity: EUR0.19/kWh (EU ind avg 2025) · Brent reference				
Fuel — natural gas (flash only)	14-22	0	0	–
Electricity cost (EUR/t)	3.4-4.4	5-11	8-15	–
Energy cost: Brent US$70/bbl	17-26	5-11	8-15	0.50Mta: 2-4x 0.06Mta: 1.5-3x
Energy cost: Brent US$100/bbl – current	22-36	5-11	8-15	0.50Mta: 2-7x 0.06Mta: : 1.5-5x
Energy cost: Brent US$150/bbl – crisis	30-52	5-11	8-15	0.50Mta: 3-10x 0.06Mta: : 2-7x
CO_2 Emissions ($kgCO_2$/t activated clay)				
Combustion CO_2 [13-15]	110-195	0	0	–
Electricity CO_2 — EU grid (0.35$kgCO_2$/kWh)	7-8	9-21	14-28	–
Total CO_2 — EU grid ($kgCO_2$/t)	120-200	9-21	14-28	0.50Mta: 6-22x 0.06Mta: 4-14x
Process characteristics				
Temperature	750-850°C	Ambient	Ambient	–
Energy source	Natural gas + electrical	100% electrical	100% electrical	–

integration eliminates the heavy building blocks of calcination (thermal system and fuel preparation, calcination reactor, cooling). It reduces material transfers, minimises interfaces and simplifies operational control.

This innovative design structurally reduces both capital and operating costs, enabling the deployment of lighter, economically competitive installations. In the absence of any combustion facility, the CCC process exhibits a simplified risk profile, and a narrower regulatory and environmental perimeter governing industrial activities, which facilitates and accelerates the permitting process by local authorities and enables rapid, large-scale decentralised deployment.

Energy, capital and operating expenditure

The difference in industrial profile between CCC cold activation and the calcined/flash-calcined clay routes is particularly pronounced in terms of cost structure. Thermal solutions require large-scale installations to amortise high capital expenditure and thermal auxiliaries. By contrast, the CCC process runs on electricity – a portion of which is generated by solar panels installed directly on the production site – and on low-energy equipment specifically parameterised and adapted for the mechanochemical activation of clay.

Table 1 and Figures 2-5 compare the production economics and carbon footprint of flash calcination versus CCC activation across four indicators:

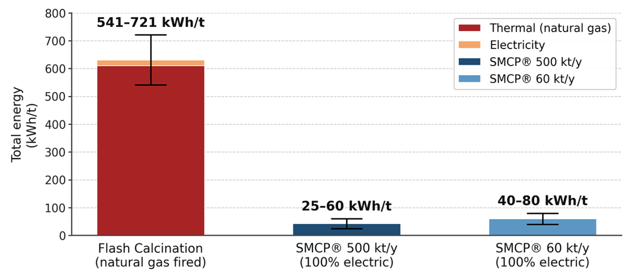
1. annualised capex (WACC seven per cent, 20 years) [1-8]
2. total energy consumption [9-11]
3. energy cost under three crude-oil price scenarios [11, 12, 16]
4. gate-to-gate CO_2 emissions.[13-15]

Process characteristics and boundary conditions are based on published literature.[17-21] Across all indicators, the CCC process exhibits a structural advantage of 3-12x on capex and 3-12x on equivalent energy compared with flash calcination, depending on production scale and local electricity tariff. This structural gap, resulting from the elimination of thermal calcination and any fossil-fuel dependence, reduces both the carbon intensity and the capital barriers at industrial scale, broadening the range of regional contexts and use cases in which a low-carbon activated clay can be produced.

Raw materials: feedstock diversity and valorisation of clay materials unsuitable for calcination

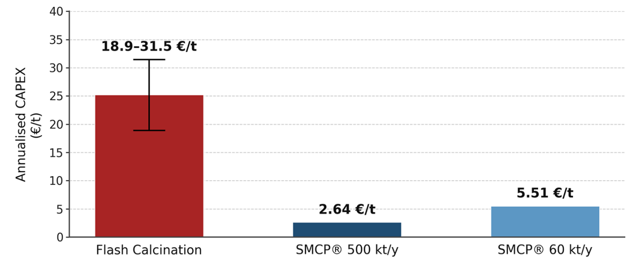
Compared with conventional calcination processes, CCC technology can process a significantly broader spectrum of clays and, more generally, of aluminosilicate raw materials (SiO_2-Al_2O_3, with variable proportions of Fe_2O_3), thereby opening the way to the valorisation of materials that were previously unexploitable, such as low-kaolinite clays and carbonate-rich clays. In practice, these deposits are often

Figure 2: total energy/t of activated clay (kWh_{eq}/t). Flash.[10-12] SMCP® 0.50Mta: 25-60kWh_e/t. SMCP® 0.06Mta: 40-80kWhe/t. SMCP®: 100% electrical



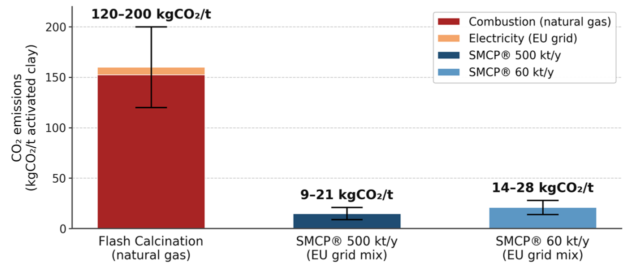
Source: Materrup

Figure 3: annualised capex (EUR/t), WACC 7%, 20 years. Flash: 7 projects.[2-9] CCC®: Materrup SAS, 2025



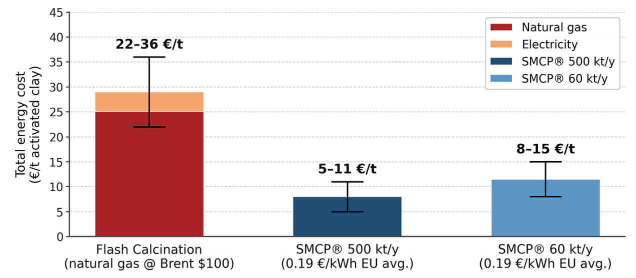
Source: Materrup

Figure 4: CO_2 emissions/t of activated clay($kgCO_2$/t). EU grid mix. Validated: NeoCem,[13] Dorfner,[14] and MDPI[15]



Source: Materrup

Figure 5: total energy cost/t (EUR/t) at Brent: US$100/bbl – gas: EUR25–40/MWh and electricity: EUR0.19/kWh



Source: Materrup

referred to by various terms (washing fines or slurries, spoils, sediments, excavation soils, mineral by-products, co-products, pozzolanic materials in the broad sense, argillaceous-calcareous fines) to describe fine fractions arising from sedimentary, weathering or mechanical processing contexts that are abundant, heterogeneous and historically little or not at all valorised.

The industrial challenge lies in converting these streams into reactive cement constituents, managing their variability through upstream quality control (characterisation, sorting, adjustment, traceability) rather than through mere semantic distinction.

Materrup has built a geological reference database of several thousand samples collected worldwide from representative clay deposits and argillo-silicate materials, covering a broad diversity of mineralogical facies and degrees of alteration: schists, natural pozzolans, sediments, overburden waste, tunnel-boring-machine excavation soils, washing by-products and argillaceous-calcareous slurries.

Tables 2 and 3 present examples of clays from different origins and illustrate, for each, the chemical and mineralogical "identity card" of representative deposits amenable to valorisation.

The potential of clay waste is evaluated through a multi-analysis approach called Materrscore®, which includes upstream physical, chemical and mineralogical characterisation coupled with reactivity indicators (including the modified Chapelle test per NF P 18-513), to secure performance consistency of the clay material regardless of the designation used in the ecosystem.

Pozzolanic reactivity: performance comparable to calcined clays

The effectiveness of CCC cold activation is demonstrated notably by reactivity testing. Raw clays exhibit limited portlandite fixation, whereas cold-activated clays show a marked increase in pozzolanic reactivity. At equivalent performance, the levels obtained can fall within the same orders of magnitude as those observed for calcined clays, or even exceed them, demonstrating that high reactivity can be achieved without thermal activation.

Table 4 presents modified Chapelle test results (NF P 18-513) for the three clays of contrasting mineralogy activated via the CCC process, compared with typical calcined clay. All three cold-activated clays

Table 2: X-ray fluorescence (chemical composition, mass %)

Parameter	Clay A	Clay B	Clay C
Origin	Quarry residue fines	Aggregate quarry waste	Sterile sedimentary clays
SiO_2 total	8.2	68.1	72
Al_2O_3	3	14.8	10.6
Fe_2O_3	2.2	2.1	4.6
Σ (SiO_2+Al_2O_3+Fe_2O_3)	13.4	85	87.2
CaO	44.5	<0.1	1.2
MgO	0	0.3	0.3
SO_3	<0.1	<0.1	<0.1
Na_2Oeq	<0.1	<0.1	<0.1
LOI	38.4	3.8	4.9

Table 3: X-ray diffraction (mineralogical phases, mass %)			
XRD phase (mass %)	**Clay A**	**Clay B**	**Clay C**
Kaolinite	–	43.3	4
Illite/micas	55.6	21.7	31
Smectites	–	–	7
Quartz	1	35	58
Carbonates	43.4	–	–

exceed the calcined clay range (650–700mg $Ca(OH)_2$/g).

Table 5 reports mortar compressive strengths and strength activity indices (SAI) measured in accordance with EN 450-1/EN 196-1, after 25 per cent replacement of CEM I 52.5R with CCC cold-activated clay. At 28 days the three clays achieve SAI values of 99-103 per cent, confirming performance parity with the reference cement.

These results are consistent with the mechanisms described for mechanochemical activation: structural disorganisation, partial amorphisation, increased effective surface area and modification of surface states.

MCC1®: concrete performance, durability and structural applications

Building on CCC technology, Materrup now produces MCC1®, a low-carbon clinker-based cement intended for structural concrete applications. MCC1 has a carbon footprint of 353kg CO_2/t of cement, while maintaining performance equivalent to that expected of a strength class 42.5 cement.

SEM-EDS analysis of six-month MCC1 paste confirms the formation of C-S-H and C-A-S-H gels, products characteristic of the pozzolanic reactivity of cold mechanochemically activated clay. The presence of the organic additive imparts a hybrid organo-mineral character to the cementitious matrix, promoting cohesive integration of the activated clay layers within the hydrated network.

Business expectations, future expansion and scalability

CCC technology has been designed for rapid, decentralised deployment. Its low capex (~EUR3.5m per 0.60Mta module), controlled opex, compact "3-in-1" module (reduced footprint) and the absence of any thermal process all contribute to shortening the permitting process and accelerating production start-up. The technology is particularly well suited to installations located close to clay deposits and consumption basins, notably on existing quarry sites, following a logic of reduced transport flows, supply resilience and a "zero quarry waste" concept.

This model facilitates international replication via modular units sized to local markets. Materrup's programme is to deploy its SMCP® units across France and throughout Europe, with the aim of upscaling production capacity internationally.

In the short term, Materrup is pursuing product portfolio expansion, notably MCC2® (42.5 class cement, ~180kg CO_2eq/t), together with the development of formulations with lower clinker content and/or incorporating alternative activators. In parallel, the company is accelerating the qualification of new clay sources and argillaceous materials in collaboration with quarry operators and value chain industrial partners.

Beyond carbon impact and material circularity, the replication of these production units will increase the availability of high-performance, cost competitive low-carbon cements in regions where cost constraints and industrial sovereignty considerations are decisive.

Within this deployment trajectory, Materrup is also developing brownfield projects for existing industrial operators unable to bear the burden of heavy carbon capture, utilisation and storage (CCUS) investments, as well as for grinding stations seeking to evolve their product strategy within very short time frames and at lower cost. Materrup provides the process design and engineering required to switch to CCC® activation: qualification and scoring of local clays, selection and optimisation of organic activation agent dosage, process-scheme definition, specifications and interfaces, utilities sizing, line retrofit, commissioning, ramp-up, skills transfer and quality control support.

Decentralised model, CCUS complementarity and economic value creation

A key feature of CCC technology lies in its decentralised industrial model. Compact, modular units can be installed directly at quarry sites or near concrete markets, reducing transport distances and associated emissions.

Cold-activated clay cements are complementary to CCUS strategies: by reducing clinker demand, they lower baseline emissions today and improve the economic efficiency of future "zero-

Table 4: modified Chapelle test results (NF P 18-513) on three clays (mg $Ca(OH)_2$/g)				
XRD phase (mass %)	**Clay A**	**Clay B**	**Clay C**	**Typical calcined clay reference**
Cold-activated clay (CCC® process)	820	840	916	650–700

Table 5: mortar strength and water demand after 25 % replacement of CEM I with CCC® cold-activated clay					
Mortar tests (EN 450-1/196-1)		**CEM I 52.5 R**	**Clay A**	**Clay B**	**Clay C**
Reference CEM I (%)		100	75	75	75
CCC® activated clay (%)		0	25	25	25
Compressive strength (MPa)	1 day	35	39	38	38
	2 days	46	46	48	49
	7 days	56	52	57	56
	28 days	63	62	64	65
SAI (%)	1 day	–	111	107	110
	28 days	–	99	101	103

CO_2" clinker-based cements (via CCUS) by enabling the "dilution" of a highly energy-intensive active ingredient with activated clays that are themselves extremely energy-efficient.

Economically, CCC enables a highly competitive cost structure: low capex, low opex and valorisation of local clay materials often regarded as industrial liabilities (stockpiling/deposits). This competitiveness provides an immediate response to inflationary pressures in Europe, while also reinforcing the relevance of the technology in contexts where cement prices are structurally lower than in Europe, notably in many emerging economies.

Conclusion

Materrup's CCC technology demonstrates that cold activation of clays – mobilising mechanical and chemical mechanisms – can produce low-carbon cements with high reactivity, supported by a compact, robust and decentralised industrial model. Invented in 2018, industrialised since 2022 and proven on hundreds of construction sites, CCC stands as a breakthrough technology: cold activation is an existing industrial pathway, immediately available for deployment.

Beyond the structural reduction of clinker dependence, CCC has systemic reach: it improves the economics of CCUS trajectories by reducing, at equivalent cement/concrete performance, the volumes of CO_2 to be captured, transported and stored. Above all, it shifts the economic equation of cement. Less embodied CO_2 and energy mean less exposure to price shocks, supply-chain dependencies and geopolitical tensions — hence a material that is more accessible, more predictable, more resilient and less exposed to the volatility of imported SCM (slag, fly ash) supply chains. By valorising widely available and locally under-utilised clay materials with controlled capital intensity, CCC meets the requirements of a low-carbon, circular cement that is at once economical, robust and scalable: a cement that transforms "waste" into a resource, secures value chains and enables a pragmatic relocalisation of production close to the point of need. ■

Table 6: advantages of CCC® technology

Dimension	CCC® advantage	Detail
Environment	CO_2 reduction	Clinker substitution up to 70%, ie –572 $kgCO_2eq/t$ (current France Ciment 2026 figures)
Environment	Zero harmful emissions	No combustion → elimination of NO_x, SO_2, VOC emissions
Process	100% electric	Cold activation without combustion; fully electric process, solar-energy compatible
Feedstock	Raw-material flexibility	Kaolinitic, illitic, muscovitic and mixed clay waste – no minimum kaolinite or maximum carbonate threshold
Product	Improved workability	Water and adjuvant demand lower than that of calcined clay
Supply chain	Local valorisation	SCM security, reduced import dependence, short supply chains (<50km)
Economic	Capex + opex	Total cost of ownership 3-5x lower than calcined-clay lines
Industrialisation	Modular platform	SMCP® architecture: greenfield deployment and brownfield retrofit

Figure 6: SMCP Landes, France

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