Carbon Neutral Materials

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Overview

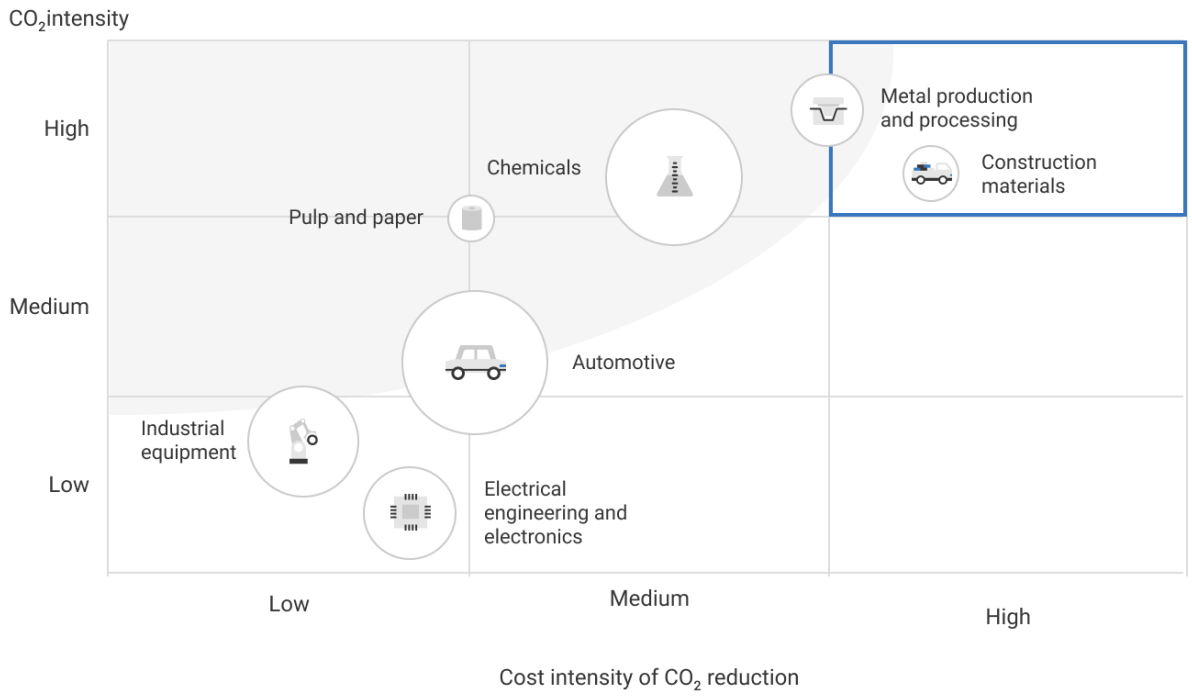
Material Production Emitting Significant GHG, Making Carbon Neutral Materials Vital to Meet the Net-Zero Target

In alignment with the 2015 Paris Agreement's objective of achieving net-zero greenhouse gas (GHG) emissions by 2050, there is a growing emphasis on carbon neutrality from both countries and companies. In this context, the global heavy industry plays a significant role, as its materials are critical inputs in major value chains (construction, automobiles, etc.), contributing significantly to global GHG emissions. To achieve carbon neutrality (net-zero), a balance should be maintained between the CO2 emissions stemming from these materials and those removed/absorbed from the atmosphere.

Materials can achieve carbon neutrality using either 1) alternative bio-based materials or 2) alternative processes or technologies. Compared to conventional materials, Carbon Neutral Materials (CNM)s have a minimal negative impact on the environment and society regarding their production process, usage, and disposal.

The intensity of CO2 emissions in material production and the cost intensity of CO2 reduction in "hard-to-abate" industries like construction materials and metal production and processing make them the key focus of this report. Further, this trend will examine the processes and technologies driving the net-zero transition, mainly focusing on cement, concrete, and steel.

Industry Sectors' Intensity in GHG Emissions and Cost Intensity of CO2 Reduction



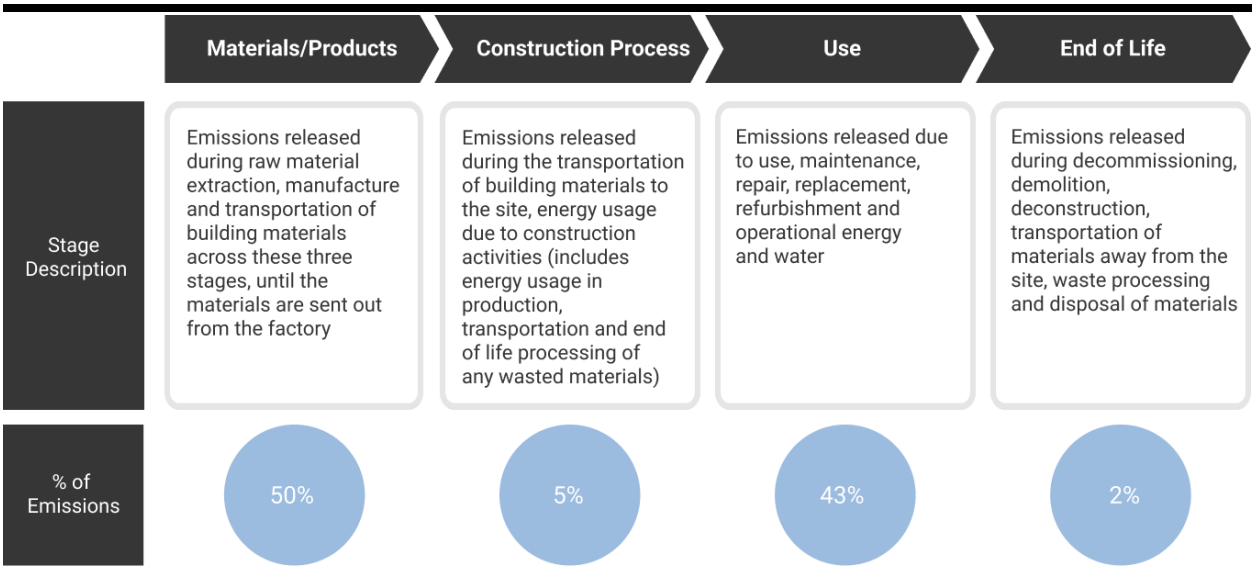
Source: Roland Berger

Construction Materials Essential But Harm the Environment Through Emissions

Industries must examine their entire life cycle to gauge their CO2 emissions accurately. Significant emissions within value chains stem from the extraction of raw materials and the production process. More specifically, when it comes to the construction life cycle, around 50% of CO2 emissions are produced at the raw material extraction, manufacture and transportation of building materials stage.

Furthermore, the construction industry is heavily reliant on cement, iron, and steel, as essential building materials that are challenging to substitute and are often mass-produced to meet demand. These materials contribute significantly to greenhouse gas emissions throughout their life cycle, making it imperative to explore carbon-neutral alternatives.

CO2 Emissions at Each Stage of the Construction Life Cycle



Source: The Institution of Structural Engineers
Note: Data as of July 2020

Policies and Legislation Governing CO2 Emissions Enabling Materials' Net-Zero Shift

Policies and legislation facilitate the demand for CNM. The carbon tax system is a prominent financial tool for controlling global CO2 emissions. While carbon taxes have existed for some time, their application is more widespread in the EU. The EU's early adoption of carbon taxes and the establishment of the emission trading system (ETS; Refer to the trend on ETS for more details) reflect their proactive steps toward achieving net-zero materials transition.

Key Policies and Legislation Controlling CO2 Emissions

Region/ Country	Policy/Legislation	Description
Global	Carbon Tax	Carbon taxes play an important role in reducing CO2 emissions in construction. For instance, high carbon taxes in countries like Sweden and Switzerland drive demand for CNM
	Global Cement and Concrete Association (GCCA) Sustainability Charter	Outlines sustainability requirements to be met by GCCA members, mainly covers: 1) Health and Safety, 2) Climate Change and Energy, 3) Social Responsibility, 4) Environment and Nature, and 5) Circular Economy
EU	European Green Deal	Aims to boost the efficient use of resources or materials in the construction industry by shifting to a circular economy
	The Ecodesign Directive	Product performance framework to be followed by construction material manufacturers. Aims to minimise any negative environmental impact during product manufacture, use, and disposal
USA	Resource Conservation and Recovery Act (RCRA)	Controls any solid or hazardous waste from the cradle to the grave of the construction life cycle
China	General Code for Building Energy Conservation and Renewable Energy Utilisation	Regulates carbon emissions from buildings and construction using policies and standards to control carbon emission intensity

Source: Compiled by Uzabase based on information from the World Bank, Global Cement and Concrete Association, and Environmental Protection Agency

Sustainability Certification for Brand Building Encourages Green Practices Across Value Chains

Building owners and construction companies use third-party product certifications to determine whether the construction materials they use are sustainable for the future or sustainably produced. There are two major types of sustainability certifications in the market.

The first type is specifically applicable to materials. For CNM manufacturers, securing one or more of these certifications is crucial for building their brand. While numerous certifications and standards are available, choosing the right accreditation is important to build trust and credibility among end-users.

The second applies to overall buildings and not specifically to building materials. For instance, the US Green Building Council's Leadership in Energy and Environmental Design (LEED) certification applies to buildings. However, they manage the LEED Credit Library, offering material manufacturers insights on sourcing to aid LEED certification.

Examples of Sustainability Credentials Encouraging Green Practices

Region/ Country	Standards/Certification	Description
International	Cradle to Cradle	Promotes a circular economy model encouraging the use of recyclable construction materials or materials which can preferably be upcycled
	Leadership in Energy and Environmental Design (LEED)	Implemented in several developed countries to certify the energy efficiency of buildings and encourage the reduction of greenhouse gas emissions
	Building Research Establishment Environmental Assessment Method (BREEAM)	This framework encourages best practices to obtain reliable environmental certification for buildings based on the usage of sustainable materials
	BRE Global Certified Environmental Profile	Scheme which certifies construction materials based on the entire life of materials, ranging from the material's extraction and manufacturing to its use and disposal
Europe	natureplus	Provides assurance that construction materials with this label are environmentally friendly
	GreenSpec Pass	Identifies and endorses green building materials based on their environmentally friendly qualities
	DGNB: German Sustainable Building Council	Promotes sustainable building practices in Europe by evaluating and certifying buildings based on their process, ecological, functional and sociocultural aspects, and technical quality
US	The CarbonFree Product Certification	Aims to heighten awareness of product emissions while recognising companies taking steps to curb emissions
Japan	Carbon Neutral Certification Program	Requires a life cycle analysis of construction materials to calculate CO2 emissions from raw materials, electricity, fuel, and waste utilised in the production or distribution of materials

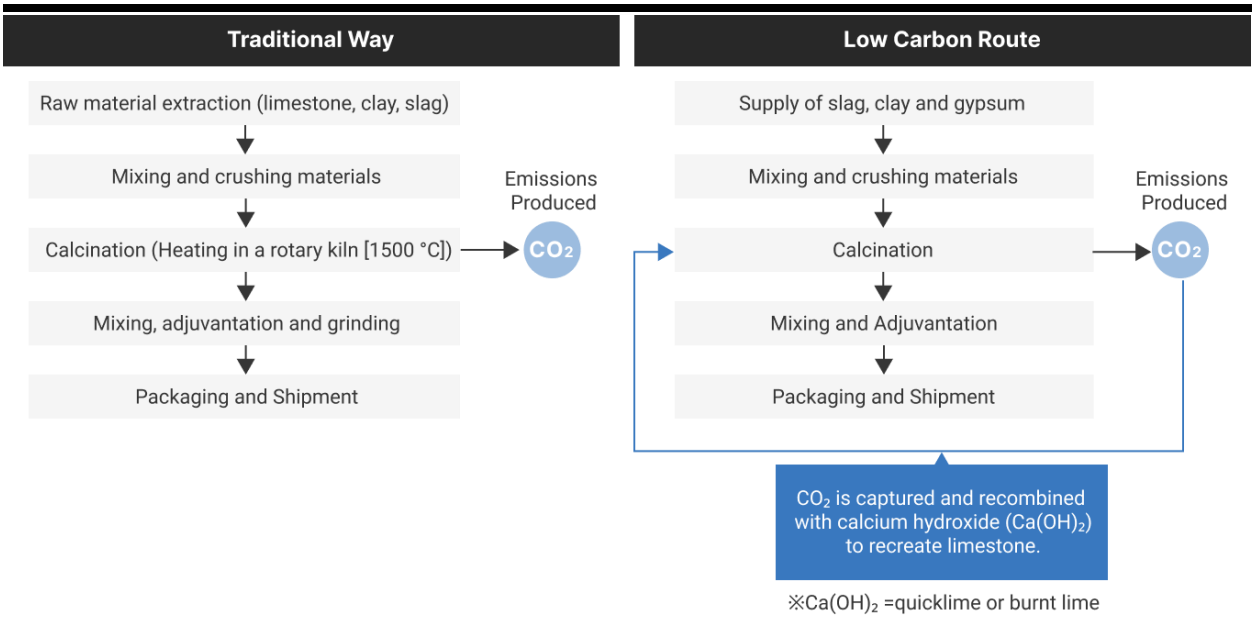
Source: Compiled by Uzabase based on data from Archtoolbox, Sustainable Investment Group, and Ecolabel Index

Technological Advancements Enable CNM Development

Technologies for CO2 reduction differ by industry. For instance, the processes and technology used in cement production vary from those utilised in steel production.

Information service provider IHS Markit noted that around half of the CO2 emissions in traditional cement production occurred during the chemical process of calcination (clinker production), and the rest from the energy-intensive heat required in the manufacturing process. However, companies like Holcim (CHE) use a low-carbon route to produce green cement, utilising technology that captures and recombines emissions produced at the calcination stage with calcium hydroxide to recreate limestone. The limestone is subsequently fed into the calcination process, minimising carbon emissions.

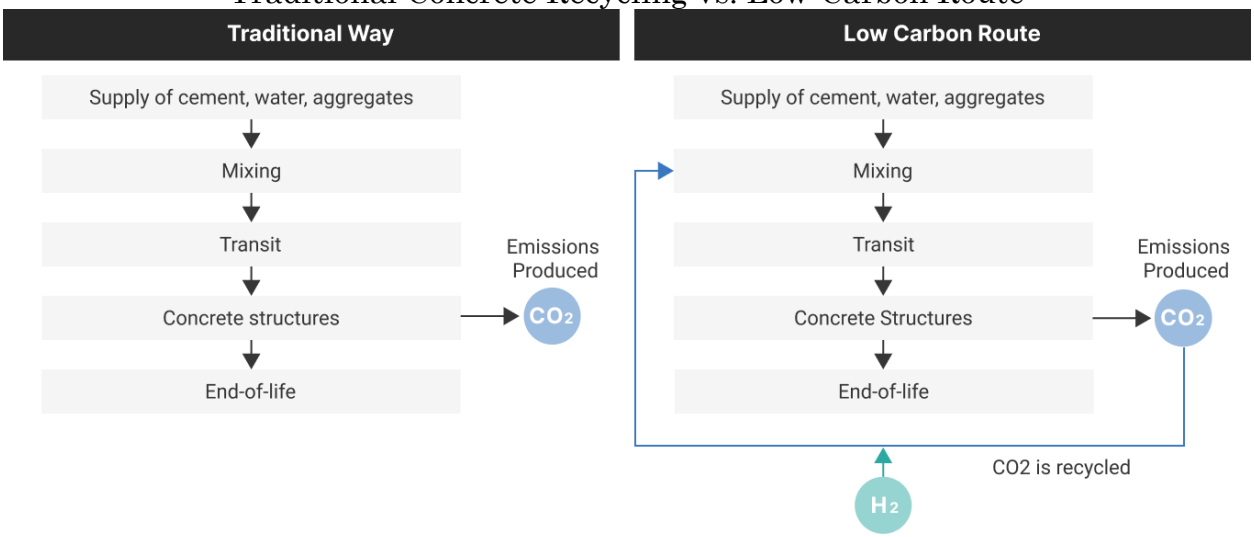
Traditional Cement Production vs. Low-Carbon Route



Source: Compiled by Uzabase

By contrast, concrete can generally absorb all CO2 emissions generated during cement production through a natural process (when concrete reacts with CO2 in the air) called carbon uptake or concrete carbonation. The carbon uptake process happens at varying speeds, occurring quite fast on non-reinforced or thin surfaces and slowly on reinforced or thicker surfaces. Carbon uptake can also take place through the exposure of demolished reinforced concrete structures to the air, and the carbon uptake volume is even higher when crushed concrete is left exposed to the air prior to being reused. The absorbed CO2 can be recycled and introduced into fresh concrete, eliminating carbon emissions. CarbonCure (CAN) is one of the firms that produces technology that facilitates this process.

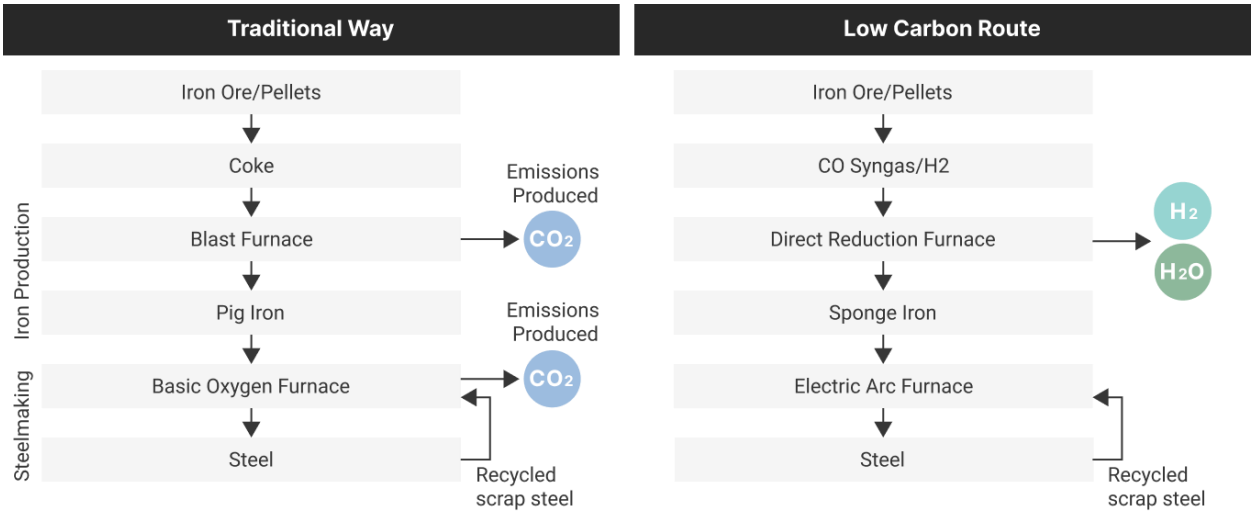
Traditional Concrete Recycling vs. Low-Carbon Route



Source: Compiled by Uzabase

Furthermore, in traditional steel manufacturing, CO2 emissions occur during iron production and steelmaking via a blast furnace (BF) and basic oxygen furnace (BOF) using coke as a fuel. However, the low-carbon route uses a mixture of carbon monoxide and hydrogen as the reducing agent in the direct reduction process to produce direct reduced iron (DRI) or sponge iron, which is melted in an electric arc furnace (EAF) to make steel. Therefore, the shift from a BF to an EAF, the use of carbon monoxide and hydrogen, and the increased utilisation of DRI in steelmaking by companies like Arcelormittal (FRA) will help achieve net-zero emissions.

Traditional Steel Production vs. Low-Carbon Route



Source: Compiled by Uzabase

In tandem with these advancements, Boston Metal (USA) has unveiled Molten Oxide Electrolysis (MOE), an innovative one-step process that harnesses clean electricity, eliminating the need for fossil fuels like coal. By leveraging renewable electricity, MOE bypasses traditional steelmaking methods such as coke production and blast furnace reduction. With commercialisation slated for 2026, Boston Metal's MOE innovation signifies a substantial adavacement toward achieving net-zero carbon emissions in the steel industry.

Biotechnology and CCUS Possess Potential but Face Obstacles

There are also several startups using biotechnology to produce materials. For instance, Biomason (USA) uses microorganisms to grow sustainable structural cement materials, while Iron Shell (USA) produces a cement alternative from waste steel dust. Nevertheless, there is uncertainty over whether they can scale up production.

Meanwhile, Carbon Capture, Utilisation, and Storage (CCUS) can be utilised by different industries (refer to the trend on Climate Tech: CCUS for more details on CCUS technology). However, using CCUS in cement production more than doubles its cost, which is why manufacturers are exploring alternative carbon reduction tools with different technology readiness levels.

Monetisation

CNM's Global Market Penetration to Increase; North America its Main Market

According to Fortune Business Insights and IMARC Group, the global green building materials (proxy for CNM) market accounted for around 26% of the total building materials market in 2023 and is expected to grow to 38% by 2032. As the shift to net-zero emissions gains momentum, demand

for green building materials is expected to grow at a CAGR of around 8% over 2023–32. This growth rate is half the projected growth rate of the building materials market as a whole during the same period.

Regionally, IMARC Group revealed that North America held the highest share of the green building materials market in 2023. This is attributable to the increasing need for environmentally conscious and energy-efficient buildings that optimise value while minimising environmental consequences. Meanwhile, Europe is an emerging growth market within this domain owing to the growth in government initiatives supporting eco-friendly build materials.

Nevertheless, factors like a lack of regulatory pressure and conflicting building codes in some countries, an expected high payback period, fears for the performance of green materials, and uncertainty over the supply of green building materials can limit growth in certain markets.

However, given global climate goals and the pursuit of carbon neutrality by 2050, the penetration rate of green building materials is expected to rise continuously alongside these aims. Further, rising awareness of green building materials and their benefits, as well as growing certainty in their supply is likely to gradually boost CNM demand.

Potential Market for Green Building Materials

	As of 2023	Forecast for 2032
Global Building Materials Market Size (USD Billion) (1)	1,320	1,867
Global Green Building Materials Market Size (USD Billion) (2)	346	716
Market Penetration (2)/(1)	26%	38%

Source: Compiled by Uzabase based on data from Fortune Business Insights and IMARC Group

CNM Growing More Economical as Carbon Taxes Rise

The framework below will typically be of use to building owners and construction companies seeking to enter the CNM market. This will help identify the cost difference between conventional materials and CNM while also assessing whether using or investing in CNM makes sense if the carbon tax surges in the future.

Cost of Using Conventional Materials vs CNM with the Impact of Carbon Taxes

Example: A House in Europe
- The average size of a house is assumed to be around 1,000 square feet.
- The key building materials used to construct a basic single-family house are assumed to be cement, steel, and bricks.
- The above is not an exhaustive list of materials.

Construction Material	Cement	Steel	Brick	Total Cost
Quantity Required (Tonne) (1)	20	4	22	
CO2 Emission Per Tonne (Tonne) (2)	0.6	1.9	0.3	
Total CO2 Emissions (Tonne) (1) x (2) = (3)	12.0	7.6	6.6	
Carbon Tax Per Tonne (USD) (4)	133	133	133	
Total Carbon Tax (USD) (4) x (3) = (5)	1,596	1,011	878	3,485
Total Cost Using Conventional Materials (CM)				
Price Per Tonne (USD) (6)	127	422	167	
Total Cost (USD) (6) x (1) = (7)	2,540	1,688	3,674	7,902
Total Cost + Carbon Tax (USD) (7) + (5) = (8)	4,136	2,699	4,552	11,387
Total Cost Using Carbon Neutral Materials (CNM)				
Price Per Tonne (USD) (9)	381	738	208	
Total Cost (USD) (9) x (1) = (10)	7,620	2,952	4,576	15,148
Cost of CNM - Cost of CM (10) - (8) = (11)				3,761
Current Carbon Tax/Total cost of CM (5) / (7) = (12)				44%
% of Carbon Tax That Makes CNM Cost Beneficial [(11) + (5)] / (7)				92% and beyond

Source: Compiled by Uzabase
Note 1: Carbon tax rate considered is for Sweden as of March 2023
Note 2: Material quantities were calculated based on an example provided by a house construction and design company
Note 3: Prices of conventional materials and CNM were collated from European countries

CNM production requires advanced processes and technologies, which generally keep the production cost high, leading key material manufacturers to pass on the cost to consumers by raising CNM prices. For example, according to the table above, CN cement is priced 200% higher, CN steel 75% higher, and CN bricks 25% higher than the prices of their conventional counterparts.

Higher CNM prices drive material users to select conventional materials despite their environmental concerns. Nevertheless, impelled by net-zero and climate goals, many countries have started imposing carbon taxes to control CO2 emissions.

For instance, Sweden charged a carbon tax of around USD 133 per tonne of CO2 emissions as of March 2023. However, material users may continue using conventional materials as long as they remain economical or cheaper, even while paying taxes.

However, given that there is a climate goal to be met by 2050, countries are more likely to hike carbon tax rates over time, and/or limit or prohibit the usage of non-CNM, to further control carbon emissions. Subsequently, there will come a break-even point, after which it will be economical and beneficial to use CNM, or even if it is not cost beneficial, they cannot use it. For instance, as shown above, when (12) increases to 92% from the current 44%, it will break even. Any increase beyond the break-even point will make it economical for the building owner or developer to use CNM.

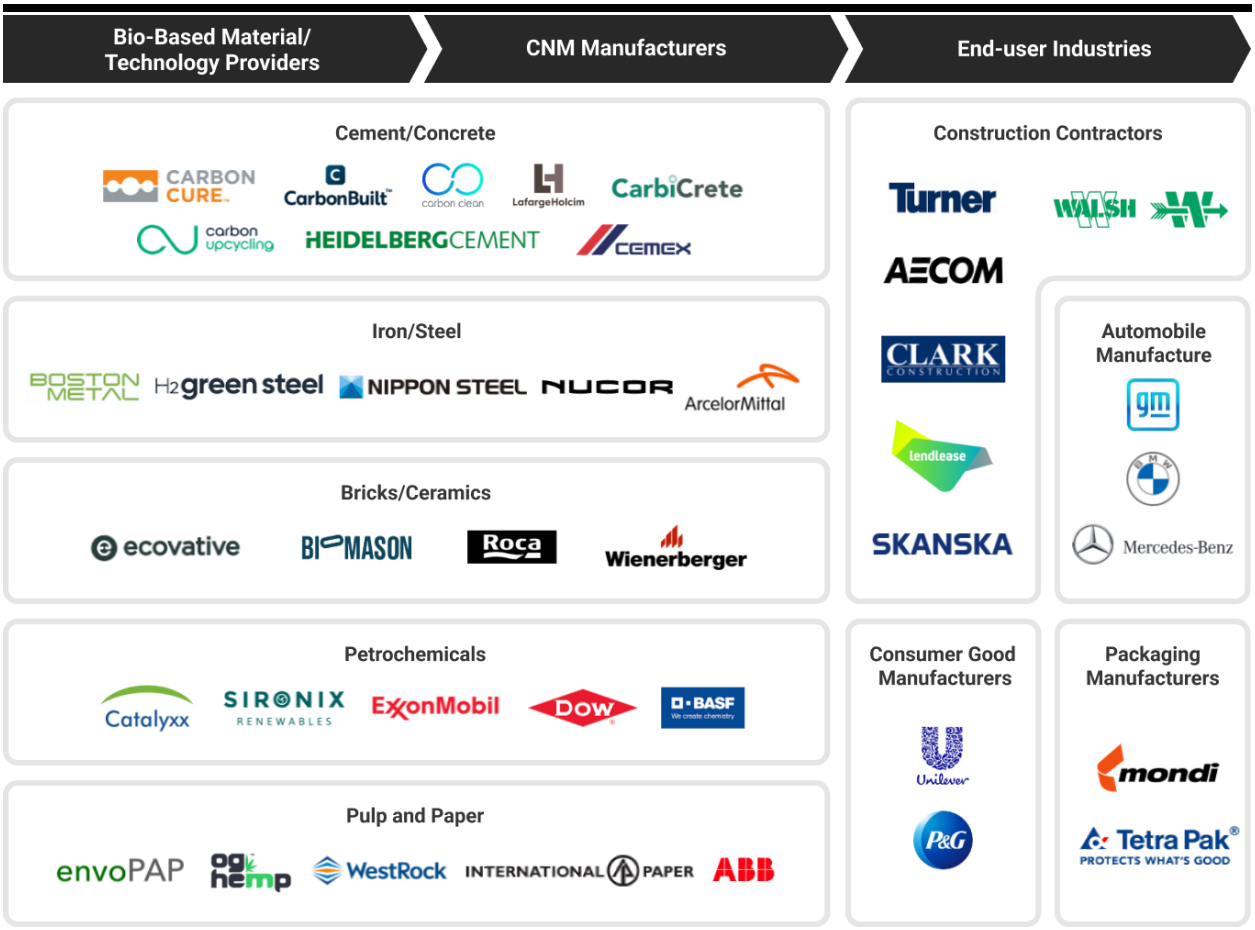
Future

Incumbent CNM Manufacturers Collaborate with New Market Entrants to Access Innovative Technology

Incumbents in the cement and steel industries have started collaborating with startups specialising in carbon-reducing technologies. Most collaborations were formed to gain access to CCUS. For instance, Holcim partnered with Solidia Technologies (USA) to lower CO2 emissions from kilns during cement production and to capture CO2 emissions from concrete manufacturing. However, some collaborations were forged between CNM manufacturers and biotechnology firms. For instance, IBF (DNK) partnered with Biomason, the owner of Biocement made using natural organisms and biotechnology, to curb carbon emissions.

In general, incumbent manufacturers involved in these partnerships are mainly from Europe, while technology startups are mostly from North America. This implies that European manufacturers are ahead in getting towards their carbon neutrality targets. Currently, most collaborations take place within the cement or concrete industry. However, going forward, this trend will likely spread across other industries.

CNM-Related Value Chain



Source: Compiled by Uzabase

Automobile Manufacturers Link with Steel Manufacturers to Chase Carbon Neutrality Goals

As global climate goals and corporate climate goals are set, the demand for CNM and net-zero production processes is expected to rise. This trend is expected to foster partnerships between industries with high demand and CNM manufacturers, enabling them to work together towards achieving carbon neutrality objectives.

For instance, the automobile manufacturer BMW (DEU) partnered with Salzgitter (DEU) and H2 Green Steel (SWE) in 2022, with the objective of using low carbon steel to meet over 40% of demand at European plants by 2030E. This aims to cut up to 400,000 tonnes of CO2 emissions annually.

Similarly, Mercedes-Benz (DEU) partnered with H2 Green Steel in 2021, with the objective of using low carbon steel in various vehicle models and to make use of supplier's CO2 reducing technology. This partnership aims to bring down emissions, to achieve a carbon-free fleet of vehicles by 2039E.

Furthermore, General Motors (USA) is adopting Nucor (USA)'s Econiq net-zero steel, which uses recycled scrap-based electric arc furnace technology to operate at 70% below industry greenhouse gas intensity. Econiq steel extends emissions reductions by utilising 100% renewable energy and high-quality carbon offsets to neutralise remaining production emissions.

Growing Interest in Clean Concrete with the Shifting Focus to Sustainability

In the past, concrete-focused start-ups and investors did not pay significant attention to the industry due to its association with heavy infrastructure and high capital requirements. However, the reality of living in a physical world and the environmental challenges humanity faces have pushed for greater efforts to maintain a sustainable environment. This has led to increased interest in "clean concrete". Recent funding for clean concrete start-ups has reached USD 436 million collectively as of July 2023, with 70% secured over 2021–23.

Few Clean-Concrete Startups That Secured Funding Over 2021–24

Company	Focus
Sublime Systems (USA)	Aims to cut CO2 emissions by introducing an electrochemical system to produce lime, a key ingredient in cement, using renewable electricity and carbon-free calcium sources
Minus Materials (USA)	Uses microalgae to create biominerals capable of storing CO2, which are then applied within the cement and concrete sector
Prometheus Materials (USA)	Creates bio-cement that emits no carbon (alternate to traditional cement production), thereby lowering global CO2 emissions
AICrete (USA)	Sole platform offering a recipe-as-a-service, optimising local resources for eco-friendlier and economically efficient concrete production
Material Evolution (GBR)	Seeks to reduce carbon emissions in the cement industry by utilising Artificial Intelligence (AI) and Machine Learning (ML) technologies.

Source: Compiled by Uzabase based on Crunchbase News 'Clean-Concrete Startups Cement Their Status' and Crunchbase

Circular Economy Key to Accelerating Net-Zero Journey

The production of new materials generate CO2 emissions. Therefore, reusing materials that have already been produced is essential, which makes a circular economy superior to a linear economy. A linear economy is one in which raw materials are extracted, used in the production of products, and disposed of immediately after use. Conversely, a circular economy ensures that products/materials are not discarded as waste, instead reused as raw materials for new products. Accordingly, adopting a circular economy, as opposed to a linear model maximises reusability, while minimising the production of new materials.

According to the 2023 Circularity Gap Report, the world was 7.2% circular, down from 9.1% in 2018. This worsening situation indicates the presence of a huge circularity gap and the potential to implement circular economy solutions to minimise waste, which ultimately leads to a reduction in emissions.

For instance, Holcim and Taiheiyo Cement (JPN) launched initiatives to benefit from the circular economy concept. Holcim partnered with the carbon capture solutions provider Carbon Clean (GBR) to capture CO2 emissions during cement production, which are then repurposed for application in

greenhouses, enhancing crop yield. Meanwhile, Taiheiyo Cement partnered with Tokyo Gas (JPN) to convert CO2 emissions resulting from cement production to synthetic methane.

These solutions showcase the potential of the circular economy to shrink carbon emissions, eventhough such applications are rarely seen at present. Therefore, expanding investment in circular economy initiatives is crucial to accelerate the move to net-zero.