Proceedings of the 5th International Conference on Art, Design and Social Sciences
DOI: 10.54254/2753-7064/2026.39333

Full-Chain CCUS Pathways for Coal-Fired Power Plants in China and Abroad

Sishu Ren

School of Architecture and Planning, Fujian University of Technology, Fuzhou, China
3240802123@stu.fjut.edu.cn

Abstract. Decarbonizing coal-fired power plants will largely determine how far the power sector can cut emissions under China's "dual-carbon" goals, and carbon capture, utilization, and storage (CCUS) offer one of the few routes to deep reductions at these facilities. This paper compares the full-chain CCUS pathways adopted in China and in Europe and the United States. The two pathways are compared qualitatively across capture, transport, utilization and storage, and policy support. A semi-quantitative framework is then built around three first-level indicators (technological maturity, cost-effectiveness, and local adaptability) and 12 second-level indicators, using weighted scoring, with particular attention to whether solid-waste mineralization can be extended downstream to cut embodied carbon in buildings. The pathways diverge because resource endowments, industrial foundations, and institutional environments differ rather than because one side simply leads in technology. Under the indicator set and weights used here, the European and North American pathway scores 3.51 and the Chinese pathway 3.13. The former scores higher on maturity and economics, the latter on local adaptability; neither is optimal everywhere. Enhanced oil recovery (EOR)-based configurations fit the oil- and gas-bearing west, whereas mineralization fits the solid-waste-intensive east. Extending mineralization into construction is feasible in principle, with a modeled comprehensive reduction of 0.8-1.2 t CO_2-equivalent per tonne of CO_2 mineralized, but the applications remain small-scale demonstrations rather than deployable systems. The results offer a reference for deploying CCUS in a region-specific manner in coal-fired power generation.

Keywords: CCUS, solid-waste mineralization, embodied carbon in buildings

1. Introduction

Coal-fired power still occupies a central place in China's energy system, so progress on the country's emissions targets depends heavily on how thoroughly these plants are decarbonized. CCUS removes CO_2 from flue gas and routes it to subsequent utilization or geological storage, giving high-emitting sectors such as coal power a route to deep reductions; the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) both treat it as a key enabling technology [1, 2]. Yet it is not a route to "near-zero emissions" by itself. Capture efficiency, energy use, transport arrangements, and the chosen utilization or storage pathway all shape the emissions that actually result.

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-7064/2026.39333

CCUS has not evolved along a single path. In Europe and North America, mature oil and gas industries and ample storage capacity have produced commercial routes built around CO_2-enhanced oil recovery (EOR) and storage in deep saline aquifers [3, 4]. China starts from a different position: coal is plentiful but oil and gas are scarce, industrial solid waste has accumulated in large volumes, and the emission sources concentrated in the east sit far from the utilization and storage sites available in the west. Copying the Western model is therefore not a realistic option. The localized route examined here pairs EOR in the western regions with mineralization of solid waste in the east [5].

Most earlier work compares parameters at a single technical stage—post-combustion capture, for example—rather than treating capture, transport, utilization, and policy as a connected pathway, and full-chain quantitative comparisons remain scarce. The emissions effects have also rarely been followed downstream into building materials and embodied carbon [6-8]. This paper addresses both gaps. It compares the Chinese and Western full-chain pathways, builds a semi-quantitative framework around technological maturity, cost-effectiveness, and local adaptability, and asks how far solid-waste mineralization can be extended along the construction value chain and where its applicability ends. The aim is to inform a differentiated, rather than uniform, deployment of CCUS in China's coal-fired power sector.

2. Theoretical foundations and literature review

2.1. Definition of core concepts

As a set of end-of-pipe technologies, CCUS targets the emissions released by fossil-fuel combustion and industrial processes. The climate roadmaps issued by the IPCC and the IEA place it among the limited options capable of delivering deep rather than marginal reductions [6, 9].

Embodied carbon covers the emissions produced before a building is handed over for use—manufacturing and processing of materials, their transport and distribution, and on-site construction. Within this total, the process emissions released in making cement, gypsum, and other binders account for a large share [8]. Past efforts to decarbonize buildings concentrated on energy efficiency during operation. As the scope for operational savings narrows, the embodied carbon tied to building materials has become a more prominent target. CO_2 captured at coal-fired plants can be converted, through mineralization with solid wastes such as phosphogypsum and steel slag, into carbonate products suitable for building materials. This links the decarbonization of coal-fired power, the utilization of solid waste, the production of low-carbon materials, and emissions reduction in the building sector into a single cross-sector chain.

2.2. CCUS technical pathways for coal-fired power plants

Three capture routes are relevant to coal-fired plants, but they are not equally mature, equally costly, or suited to the same settings. Post-combustion capture is the workhorse: it pulls CO_2 directly from the flue gas after coal combustion, and amine-based chemical absorption is the leading variant. Because it leaves the existing combustion system untouched, it is the natural choice for retrofitting units already in service, and it is currently the most widely used and mature option for engineering deployment [6, 10]. Oxy-fuel combustion takes a different approach, burning the fuel with high-purity oxygen rather than air so that the flue gas is already concentrated in CO_2 and separation is simpler. The trade-off is substantial energy use and capital cost, and the route remains at the industrial demonstration stage, although it is also attractive for cement kilns and similar industrial

DOI: 10.54254/2753-7064/2026.39333

facilities [6, 10]. Pre-combustion capture, by contrast, is tied to integrated gasification combined cycle (IGCC) plants: CO_2 is removed after gasification, before the syngas is burned for power. Separation is then comparatively cheap, but the system is complex and capital-intensive, and it fits mainly new, large-scale build rather than retrofit—which is why it has yet to be deployed widely [6].

Utilization and storage determine whether CCUS can ever pay for itself. For carbon capture and storage (CCS), geological utilization is currently the route that does so. Dominated by CO_2-enhanced oil recovery (EOR), it injects CO_2 into oil reservoirs to raise output while storing the gas in the process, and the oil revenues offset part of capture cost. The Global CCS Institute reports that over 60% of CCS projects in commercial operation worldwide rely on EOR, mostly in North America, where the oil and gas industry supplies the underlying infrastructure [3]. Geological storage proper—injection into deep saline aquifers or depleted oil and gas reservoirs for long-term retention—offers the largest theoretical capacity but produces no saleable product, so it rests almost entirely on carbon taxes, subsidies, or trading revenues [3]. The remaining two routes are less developed. Chemical utilization turns CO_2 into products such as methanol and biodegradable plastics, but the volumes it can absorb are limited and the life-cycle rebound effect is disputed, so it is largely confined to demonstrations [7]. Mineralization, the route most relevant to China's industrial structure, reacts CO_2 with calcium- and magnesium-bearing minerals or solid wastes to form stable carbonates. It removes the risk of geological leakage, consumes solid waste, and can yield materials for building products [8, 10].

Source–sink matching is the framework that guides where CCUS is built. It arranges the spatial layout and capacity of CO_2 sources relative to the sinks that use or store them, so as to hold down transport cost and keep projects viable [5]. As Su et al. note, the geography is uneven: the east concentrates coal-fired plants and industrial sources but has little oil, gas, or suitable storage, while the west holds the oil, gas, and storage capacity but has more dispersed sources. This mismatch is the main reason that regional CCUS pathways in China have to differ [5].

3. Full-chain CCUS pathways for coal-fired power plants in China and abroad

3.1. Overall characteristics of the two pathways

European and North American countries, represented by the United States and Norway, have developed a generalized commercial pathway of "post-combustion capture + networked pipeline transportation + EOR/geological storage in saline aquifers," supported by mature oil and gas industries and carbon market mechanisms. The utilization and storage stage provides relatively clear revenue streams, while policy instruments are primarily based on market-oriented incentives. As of 2024, projects in operation or under construction in North America and Europe accounted for more than 65% of the total number of such projects worldwide [3, 4]. China's coal-fired power sector remains largely at the million-ton-per-year industrial demonstration stage for CCUS, characterized by parallel demonstrations of multiple technologies and a dual-track development of CO_2 utilization and storage pathways. On the capture side, post-combustion capture remains the primary technology, while the utilization and storage side has developed a parallel pattern of EOR in western oilfields and mineralization of industrial solid wastes in eastern regions. Among these, the pathway of producing low-carbon building materials through solid-waste mineralization has distinct local characteristics. Policy support is primarily driven by government-funded initiatives and demonstration projects, while a fully developed market-based commercial model has yet to be established [6, 11].

DOI: 10.54254/2753-7064/2026.39333

3.2. Comparison of carbon capture stages

Carbon capture technologies in Europe and North America were initially developed and commercialized in the natural gas processing, chemical, and petroleum refining industries before gradually being adopted in coal-fired power generation. Post-combustion chemical absorption is currently the dominant technology choice. Its technological development has focused on large-scale deployment and energy-efficiency improvements, with ongoing optimization of advanced absorption solvents and system-level heat integration. These efforts aim to reduce the energy consumption of CO_2 capture by 20%–30%. The U.S. Petra Nova project, with a capture capacity of 1.4 Mtpa, demonstrated the engineering feasibility of integrating CCS with large-scale coal-fired power units [3, 10]. At the same time, capture systems are planned in coordination with downstream CO_2 transportation and storage networks. They are often located within industrial clusters, enabling direct connection to regional CO_2 pipeline networks.

China's carbon capture technology for coal-fired power generation has followed an evolutionary pathway of "small-scale pilot testing and demonstration followed by gradual scale-up." Post-combustion capture is the preferred option for retrofitting existing units. Early demonstrations were mainly in the range of 0.1–0.5 Mtpa, while project capacity has increased rapidly in recent years. The 0.15 Mtpa Guoneng Jinjie project, the 1.5 Mtpa Huaneng Longdong project, and the 1 Mtpa coal-fired power project integrated with PetroChina's Xinjiang Oilfield have been successively implemented, marking the transition of China's coal-fired power sector toward the megaton-scale engineering deployment of CO_2 capture [3, 6, 11]. Oxy-fuel combustion technology has been demonstrated first in cement kiln applications. The Qingzhou Cement oxy-fuel combustion capture project, commissioned in 2024 with a capacity of 0.2 Mtpa, is reported as the largest demonstration project of its kind worldwide [3, 10]. Pre-combustion capture based on IGCC remains primarily a technology reserved for future development.

China and other countries show a high degree of convergence in the selection of carbon capture technologies, with post-combustion capture being the preferred option for coal-fired power generation in both cases. There is no fundamental technological gap in the underlying principles; the main differences lie in three areas: system energy consumption and solvent performance, the scale-up of capture equipment, and the degree of coordination between upstream and downstream processes.

3.3. Comparison of CO_2 transportation stages

CCS transportation infrastructure in Europe and North America was developed relatively early, forming an overall structure in which long-distance pipelines serve as the backbone, supplemented by regional pipeline networks within industrial clusters. In the United States, the well-developed oil and gas pipeline infrastructure has enabled the retrofitting of some existing pipelines for CO_2 transportation, contributing to the development of an interstate CO_2 transportation network [3, 4]. Europe has focused on developing cross-border offshore transportation systems, adopting a model that combines onshore pipelines, maritime shipping, and storage hubs. Norway's Northern Lights and the Netherlands' Porthos projects are both examples of open-access transportation and storage hubs [3, 4]. Under conditions of large transport volumes and relatively long transportation distances, pipeline transportation generally offers a relatively clear advantage in terms of unit transportation costs.

China's CCS transportation infrastructure remains at an early stage of development, with significant differences in transportation modes compared with those in Europe and North America.

DOI: 10.54254/2753-7064/2026.39333

At present, the vast majority of demonstration projects in China rely on road tanker trucks for CO_2 transportation, which is mainly suitable for short-distance and small-scale applications but involves relatively high unit transportation costs and limited transport capacity [5, 11]. The construction of long-distance CO_2 pipelines in China remains at an early stage, with only a very limited number of such pipelines currently in operation. Representative projects include the Qilu Petrochemical–Shengli Oilfield CO_2 pipeline. Su et al. noted that the spatial mismatch between emission sources in eastern China and utilization and storage sites in western China makes the development of long-distance CO_2 pipelines an objective requirement for future large-scale deployment. However, the planning and construction of the pipeline network currently lag significantly behind the pace of project demonstrations [5]. The transportation stage represents one of the most direct manifestations of the difference in CCS industry maturity between China and other countries. The existing gap in CO_2 pipeline infrastructure is likely to become a major constraint on the large-scale deployment of CCS at capacities exceeding the million-ton-per-year level in the future.

3.4. Comparison of CO_2 utilization and storage pathways

The CO_2 utilization and storage stage of CCS in Europe and North America is characterized by a pattern in which EOR serves as the primary commercial pathway, while saline aquifer storage provides a long-term storage option. CO_2-enhanced oil recovery (EOR) is currently one of the most commercially established pathways. In the United States, EOR has been applied for several decades, supported by the country's extensive oil industry. More than 60% of CCS projects currently in operation worldwide use EOR as the CO_2 utilization pathway, with the vast majority concentrated in North America [3]. Yang et al. estimated that EOR can offset part of the costs of CO_2 capture and transportation through revenues from oil production, although its profitability is highly sensitive to fluctuations in oil prices [9]. Geological storage in saline aquifers serves as a key pathway for long-term emissions reduction. Projects such as Norway's Sleipner project, which began operation in 1996, have accumulated extensive experience in long-term monitoring and engineering practices for CO_2 storage in saline aquifers. With rising carbon prices and the implementation of subsidy policies, the number of saline aquifer storage projects in Europe has increased rapidly [3, 4]. Other pathways, including mineralization and chemical utilization, remain primarily at the laboratory research and small-scale demonstration stages in Europe and North America.

China has not simply adopted the single-pathway EOR model used in Europe and North America. Instead, it has developed a dual-track utilization and storage structure based on its domestic industrial conditions. EOR in western oilfields is currently one of the more mature utilization pathways. Projects such as Sinopec's Qilu–Shengli Oilfield project, PetroChina's Jilin Oilfield project, and Xinjiang Oilfield projects have adopted the "coal-fired power plant capture + oilfield EOR" model. However, due to the geographical distribution of oil resources, this pathway is mainly applicable to western regions and has limited potential to serve the densely concentrated coal-fired power emission sources in eastern China [6, 11]. Mineralization of industrial solid waste represents a distinctive localized pathway in China. In response to the large volumes of industrial solid waste accumulated in eastern China and the limited availability of geological storage resources, China has focused on developing CO_2 mineralization technologies using industrial solid wastes such as phosphogypsum, steel slag, and carbide slag. Mo et al. demonstrated that the resulting mineralization products can be used as raw materials for cementitious materials and gypsum-based building materials, thereby delivering three concurrent benefits: carbon emissions reduction, industrial solid-waste utilization, and reduced embodied carbon in building materials [8]. A life-cycle assessment by Liang et al. showed that, under scenarios involving short-distance matching

DOI: 10.54254/2753-7064/2026.39333

between CO_2 sources and sinks in eastern China, the mineralization pathway using industrial solid waste offers greater overall benefits than the EOR pathway involving long-distance transportation to western regions [7]. Geological storage in saline aquifers remains at the preliminary exploration stage in China and has not yet entered large-scale demonstration [11].

3.5. Comparison of policy support systems

The development and maturation of the CCS industry in Europe and North America are closely associated with well-established policy instruments and regulatory frameworks, supported by a diverse range of market-based incentives. The United States has introduced the 45Q tax credit, which provides fixed tax incentives for geological storage projects based on the amount of CO_2 stored. The European Union has established carbon price signals through the Emissions Trading System (ETS), complemented by Carbon Contracts for Difference (CCfDs) to provide greater revenue certainty for projects. Countries such as Norway have also introduced carbon taxes to create economic incentives for emissions reductions [3, 4]. The regulatory and legal frameworks are relatively well established. The United States has established the Underground Injection Control (UIC) Class VI well permitting system for CO_2 geological sequestration, while the European Union has introduced the Net-Zero Industry Act, which sets a target of 50 Mtpa of annual CO_2 injection capacity by 2030 [3, 4]. China's CCS policy framework remains largely at the pilot and demonstration stage, characterized by a policy approach led by dedicated research and development programs and supported by demonstration projects. Current policy instruments rely primarily on fiscal subsidies and project-based support, with limited subsidy coverage. Although the China Certified Emission Reduction (CCER) mechanism was relaunched in 2024, the initial methodologies did not include CCUS projects, meaning that such projects currently cannot obtain stable revenues through carbon trading [3]. In addition, comprehensive institutional frameworks for geological storage permits, site access, and long-term liability allocation have yet to be fully established [11].

4. Evaluation of CCUS pathways for coal-fired power plants in China and abroad

4.1. Construction of the evaluation framework

Three first-level indicators are used—technological maturity, emissions reduction cost-effectiveness, and local adaptability—disaggregated into 12 second-level indicators.

Technological maturity is weighted at 0.30 and covers the maturity of capture, transport, and utilization/storage technologies together with the completeness of the supporting industrial chain. The two cost-related dimensions each receive 0.35: cost-effectiveness is built from unit capture cost, unit transport cost, the net unit cost of utilization and storage, and the static payback period, while local adaptability is built from resource endowments, industrial synergies, source–sink spatial matching, and the policy environment. The first-level weights follow settings commonly used in CCS evaluation studies, and the second-level indicators within each group are weighted equally. The scheme is admittedly subjective and can be re-weighted when the decision priority changes.

Scoring follows a weighted five-point scale. Every indicator is placed on a common scale of 1 to 5, where 5 is the most favorable and 1 the least; the second-level indicators are averaged within their group to give the first-level scores, and the final score is the weighted sum of those scores.

Because the indicators carry different units, they are put onto the common scale by type rather than by a single measurement. For continuous variables such as costs, the median of the ranges

DOI: 10.54254/2753-7064/2026.39333

reported in the literature is mapped to 1–5 by linear interpolation, with lower costs scoring higher; for positive indicators such as the Technology Readiness Level (TRL), the TRL itself is translated to the 1–5 scale.

Indicators that cannot be measured on a continuous scale—resource endowments and the policy environment among them—are scored as high, medium, or low, based on the published literature and the actual industrial setting. The cost figures are comparatively objective, whereas the technological, spatial, and policy judgments carry a degree of subjectivity. The results should therefore be read as a semi-quantitative comparison built on public information, not as a statistical measurement in the strict sense.

4.2. Evaluation results by dimension

Following the evaluation methods and data sources described above, the typical pathway combination in Europe and North America and the localized pathway combination in China were standardized and scored using weighted evaluation across three dimensions—technological maturity, emissions reduction cost-effectiveness, and local adaptability—and 12 second-level indicators. The scores for technological maturity, emissions reduction cost-effectiveness, and local adaptability are presented in Tables 1, 2, and 3, respectively. The overall weighted scores of the two pathway combinations are summarized in Table 4.

Table 1. Comparison of scores for the technological maturity dimension

Second-Level Indicator	Typical European and North American Pathway (Status/Value)	Europe and North America Score	Localized Pathway in China (Status/Value)	China Score	Score Difference
Carbon capture technology maturity	TRL 8, transferred to coal-fired power applications	4.0	TRL 7–8, megaton-scale industrial demonstration	3.5	0.5
CO_2 transportation technology maturity	TRL 9, networked pipeline operation	5.0	TRL 6–7, primarily tanker trucks; pipeline transportation at an early stage	2.5	2.5
CO_2 utilization and storage technology maturity	EOR and geological storage at commercial/large-scale deployment stages	4.5	EOR has an established engineering basis; mineralization remains at the demonstration stage	3.0	1.5
Completeness of supporting infrastructure across the industrial chain	Well-established equipment, engineering, and operation and maintenance systems	4.5	Industrial chain still under development	3.0	1.5
First-Level Indicator Score (Weight: 0.30)		4.50		3.00	1.50

Note: TRL refers to Technology Readiness Level, which consists of nine levels. A higher TRL indicates a higher degree of technological maturity.

Table 2. Emissions reduction cost-effectiveness dimension scores [5, 7, 9-11]

Second-Level Indicator	Typical European and North American Pathway (Status/Value)	Europe and North America Score	Localized Pathway in China (Status/Value)	China Score	Score Difference
Unit CO_2 capture cost	RMB 280-380/t CO_2	4.0	RMB 350-500/t CO_2	3.0	1.0

DOI: 10.54254/2753-7064/2026.39333

Table 2. (continued)

Unit CO_2 transportation cost	RMB 30-50/t (pipeline, megaton-scale, per 100 km)	4.5	RMB 80-120/t (road tanker, per 100 km)	2.0	2.5
Net unit cost of CO_2 utilization and storage	RMB 50-150/t (EOR pathway)	4.0	RMB 100-200/t (EOR in western China); RMB 150-250/t (mineralization in eastern China)	2.5	1.5
Static payback period	6-9 years	3.5	9-13 years	2.5	1.0
First-Level Indicator Score (Weight: 0.35)		4.00		2.50	1.50

Note: Cost data are ranges reported in the literature, with the median values used for scoring. Transportation costs are calculated based on a megaton-scale transport volume and a distance of 100 km.

Table 3. Comparison of scores for the local adaptability dimension [5]

Second-Level Indicator	Typical European and North American Pathway (Status/Value)	Europe and North America Score	Localized Pathway in China (Status/Value)	China Score	Score Difference
Resource endowment matching	Applicable to only a limited number of regions in western China	2.0	EOR is suitable for western regions, while mineralization is suitable for eastern regions	4.0	-2.0
Industrial synergy adaptability	Requires support from a mature oil and gas industrial system	2.5	Can leverage the building-material industry and industrial solid-waste management demand in eastern China	4.0	-1.5
Spatial matching between CO_2 sources and sinks	Poor adaptability under the spatial mismatch between sources and sinks in eastern China	2.0	The mineralization pathway enables local utilization of locally captured CO_2	4.5	-2.5
Policy environment adaptability	Highly dependent on mature carbon market mechanisms	2.5	Consistent with the current policy stage of government-led demonstration and guidance	3.5	-1.0
First-Level Indicator Score (Weight: 0.35)		2.25		4.00	-1.75

Note: A negative score difference indicates that the localized pathway in China receives a higher score than the European and North American pathway for the corresponding indicator.

Table 4. Comprehensive evaluation results for two typical pathways

First-Level Indicator	Weight	Typical European and North American Pathway Combination	Localized Pathway Combination in China	Score Difference
Technological maturity	0.30	4.50	3.00	1.50
Emissions reduction cost-effectiveness	0.35	4.00	2.50	1.50
Local adaptability	0.35	2.25	4.00	-1.75
Overall Weighted Score	1.00	3.51	3.13	0.38

DOI: 10.54254/2753-7064/2026.39333

Note: The overall weighted score is calculated as Σ (first-level indicator score × corresponding weight). The evaluation focuses on the two typical pathway combinations constructed in this paper. The scores reflect only their relative performance under the indicators, weights, and representative parameter conditions established in this paper and do not represent the overall performance of all CCUS projects in Europe, North America, or China.

4.3. Comprehensive evaluation and applicability boundaries

The overall scores of the two pathway combinations are 3.51 for the typical European and North American pathway combination and 3.13 for the localized pathway combination in China, with a difference of only 0.38 points. The evaluation does not represent the overall average performance of all CCUS projects in Europe, North America, or China. Instead, it focuses on the two typical pathway combinations identified in Section 3. The former is represented by the baseline configuration of "post-combustion capture + pipeline transportation + EOR/saline aquifer storage," while the latter is represented by the dual-track configuration of "post-combustion capture + tanker truck/pipeline transportation + EOR + solid-waste mineralization." Therefore, the scores of 3.51 and 3.13 indicate only the relative performance of the two pathway combinations under the indicator system, weighting scheme, and representative parameter conditions established in this paper. They should not be interpreted directly as indicating that CCUS as a whole in Europe and North America performs better than CCUS in China.

The advantages of the two pathway combinations are highly dependent on regional resource endowments and market conditions. The typical European and North American pathway combination is applicable to scenarios where emission sources are located close to oil and gas fields or storage sites, transportation distances are relatively short, and mature carbon pricing mechanisms are in place. In China, it is more applicable to certain western regions with favorable oil and gas resources and geological storage conditions. The China National Petroleum Corporation (CNPC) Xinjiang Oilfield Karamay million-ton-scale coal-fired power CCUS project represents a typical application of this pathway in western China. The project is equipped with two 660 MW ultra-supercritical coal-fired power units, with a Phase I post-combustion capture facility designed to capture 1 Mt of CO_2 per year. All captured CO_2 is transported over a short distance to nearby oil reservoirs in the Junggar Basin for enhanced oil recovery (EOR). The project therefore benefits from a short source–sink distance and a high degree of synergy with the oil and gas industry, with its key operational configuration closely aligned with the mainstream EOR pathway adopted in Europe and North America [12, 13]. The localized pathway combination in China is applicable to eastern regions with high concentrations of coal-fired power plants and industrial solid wastes. It can simultaneously facilitate industrial solid-waste utilization and emissions reduction in building materials, and can serve as a synergistic pathway for reducing embodied carbon in buildings. However, its main limitation is the relatively limited CO_2 utilization capacity of individual projects.

5. Building embodied carbon reduction via coal-fired power CCUS

5.1. Background of embodied carbon reduction in buildings

The carbon emissions over the full life cycle of a building consist of operational carbon emissions and embodied carbon emissions. Embodied carbon refers to the carbon emissions generated during the pre-use stages, including the production and transportation of building materials and the construction process [8, 14]. Life-cycle estimates for China's building sector over 2005-2020 put its total emissions at 5.08 $GtCO_2$ in 2020, roughly 50.9% of the national total. Embodied emissions made up the larger part of that total: building-material production emitted 2.82 $GtCO_2$ and

DOI: 10.54254/2753-7064/2026.39333

construction about another 2%, whereas building operation emitted 2.16 $GtCO_2$, so the two pre-use stages together exceeded operation. Within material production, the process emissions released by cement, lime, and gypsum were the dominant component, making these binders the leading source of embodied carbon [15]. As energy-efficiency technologies become increasingly widespread in the operational phase, embodied carbon can account for more than 50% of the life-cycle carbon emissions of low-energy and nearly zero-energy buildings, making building materials a key focus of deep decarbonization in the building sector.

The three mainstream pathways for reducing emissions from building materials—energy-efficiency improvements, clinker substitution, and fuel substitution—all face technical limitations. Cement production efficiency is already approaching its theoretical limit, while the substitution ratios of clinker with fly ash and slag have reached relatively high levels. Green hydrogen and biomass fuels are also difficult to deploy at scale in the short term. CO_2 mineralization using industrial solid wastes to produce low-carbon building materials does not require fundamental changes to existing cement production processes. Instead, it can directly mineralize CO_2 while producing raw materials for building materials, making it a complementary pathway for emissions reduction in the building-material sector. However, the technology as a whole remains at the laboratory and pilot-scale stages [8].

5.2. Cross-industry emissions reduction mechanism

CO_2 captured at coal-fired plants can be carried into the building sector through mineralization, although the chain is not equally developed at every link. It begins at the plant, where post-combustion capture separates and purifies CO_2 into a steady supply. The gas is then reacted with the calcium and magnesium in solid wastes—phosphogypsum, steel slag, carbide slag—converting it into carbonate products. From that point the two downstream links move together: the products are modified into supplementary cementitious materials or feedstock for gypsum-based goods, displacing some conventional high-carbon materials, and those materials, once used in construction, lower the embodied carbon of the finished building. In this way a single chain serves coal-fired decarbonization, solid-waste management, the decarbonization of building materials, and building-level reduction together. Mo et al. showed that, under laboratory and pilot conditions, phosphogypsum-derived products can partly replace cement clinker in concrete, delivering mineralization and solid-waste utilization at the same time [8]. None of this is net reduction by default: mineralization itself uses energy and emits carbon, so the net figure has to come from a full life-cycle assessment. For now the route can only complement, rather than replace, the conventional ways of cutting building emissions.

5.3. Building application scenarios for mineralized building materials

Based on the current state of the technology, mineralized building materials can be applied in three types of building scenarios. The first is structural engineering. Mineralization products such as calcium carbonate and calcium silicate can be modified and blended with fly ash and slag to serve as supplementary cementitious materials. Existing experiments indicate that, under certain conditions, replacing 10%-20% of cement clinker can meet basic performance requirements. However, the long-term durability of high replacement ratios still requires further validation. This represents the application direction with the greatest emissions reduction potential [8]. The second is building envelope and interior finishing applications. Calcium sulfate products obtained through phosphogypsum mineralization can be used to produce gypsum plasterboard, gypsum blocks, and

DOI: 10.54254/2753-7064/2026.39333

gypsum plaster. Their performance is comparable to that of natural gypsum and industrial by-product gypsum, allowing them to be compatible with existing production lines and used for interior partition walls, suspended ceilings, and wall plastering [8]. The third is municipal and landscape engineering. Mineralized steel slag and tailings can be pressed into permeable bricks, roadbed materials, and landscape stone products. These applications involve relatively simple processing and less stringent performance requirements, while also being compatible with sponge city initiatives and industrial solid-waste management policies, making them suitable for large-scale pilot applications.

5.4. Emissions reduction potential and practical constraints

China's conditions favor pilot work: it has the world's largest installed coal-fired fleet, a large stock of mineralizable waste, and a wide building-materials market. The life-cycle assessment by Liang et al. suggests that, under short-distance source–sink matching with conventional material substitution, each tonne of CO_2 mineralized could correspond to roughly 0.8-1.2 tonnes of CO_2-equivalent reduction. The figure is a theoretical ceiling, not a forecast, and the scale achievable today is limited by technology, standards, and cost [7]. The barriers themselves are interlocking rather than separate. The technical one is that mineralized products at high replacement ratios still need engineering proof of their mechanical behavior and durability, including freeze–thaw resistance and impermeability. Standards lag behind the technology: product standards, testing methods, and the accounting and certification of emissions reductions for these materials do not yet exist. The economics then work against deployment, since production costs exceed those of conventional materials and the unit reduction cost runs above that of EOR, leaving little market pull without subsidies [7]. Underlying all of these is an institutional gap—coal power, waste management, building materials, and construction sit in different industries, with no mature business model or agreed mechanism for sharing benefits.

5.5. Pathways for implementation and scale-up

Implementation can be advanced in stages across three levels. At the technological and standards level, 100,000–1,000,000 tpa full-chain demonstration projects should be developed to accumulate engineering data, while product standards, testing methods, and carbon accounting methodologies for mineralized building materials should be established. Differentiated guidelines for replacement ratios should also be developed according to specific building applications. At the industrial and economic level, integrated industrial parks combining "coal-fired power CO_2 capture–solid-waste mineralization–low-carbon building materials" can be developed around clusters of coal-fired power plants, phosphate-chemical industries, and building-material manufacturers in eastern China to shorten transportation distances. Low-carbon building materials should be incorporated into green procurement and carbon emissions reduction support mechanisms, while efforts should be made to promote the inclusion of emissions reductions from mineralization in the voluntary carbon market [5]. At the building adoption level, pilot applications should first be carried out in green buildings, nearly zero-energy buildings, and low-carbon industrial parks. Efforts should be made to incorporate embodied carbon in building materials into green building assessment systems, thereby creating demand-side incentives for low-carbon building materials. Overall, this transmission chain is technically feasible and applicable to multiple building scenarios, but it remains at an early demonstration stage. Its actual contribution to deep decarbonization in the building sector requires further quantification based on specific application contexts.

DOI: 10.54254/2753-7064/2026.39333

6. Conclusion and outlook

6.1. Conclusion

Through a full-chain qualitative review, multidimensional semi-quantitative evaluation, and extended analysis from an architectural perspective, this paper systematically examines the differences, performance, and applicability boundaries of CCUS development pathways for coal-fired power plants in China and abroad, and explores the theoretical feasibility of extending the solid-waste mineralization pathway to embodied carbon reduction in buildings. China and other countries have developed differentiated full-chain CCUS pathways for coal-fired power generation, and this divergence is closely associated with three factors: resource endowments, industrial foundations, and institutional environments. The differences among these pathways cannot be attributed solely to technological maturity, and the relative contributions of these factors remain difficult to determine at this stage. The European and North American pathway has advantages in technological maturity and economic performance under favorable application conditions, but shows limited adaptability to China's overall national conditions. The pathway developed in China is relatively weaker in technological maturity and economic performance, but is better aligned with the industrial conditions of eastern China. Pathway selection should be tailored to local conditions rather than blindly following international models. The solid-waste mineralization pathway has theoretical potential for emissions reduction through its integration into the building industry value chain. However, it remains at an early demonstration stage due to constraints related to technical performance, standards, economic viability, and cross-industry coordination mechanisms. Its current practical deployment scale is limited, and it cannot yet replace conventional measures for reducing carbon emissions from buildings.

6.2. Outlook

This paper provides a reference for the differentiated deployment of CCUS in coal-fired power generation and for cross-industry collaborative management of embodied carbon in buildings. However, the data used in this paper is mainly derived from median values of representative projects reported in publicly available literature, and the weighting scheme involves a certain degree of subjectivity. Future research could introduce expert scoring methods to optimize the indicator weights and conduct sensitivity analyses to identify how pathway rankings vary under different decision-making objectives, thereby improving the robustness of the evaluation. At the same time, representative cases of public buildings and residential buildings could be selected for whole-life-cycle carbon accounting to quantify the actual emissions reduction benefits of coal-fired power CCUS for embodied carbon in buildings under different application scenarios.

References

[1] IPCC. (2005). *IPCC special report on carbon dioxide capture and storage*. Cambridge University Press. Retrieved from https://doi.org/10.1017/CBO9780511535319

[2] IEA. (2020). *CCUS in clean energy transitions*. International Energy Agency. Pairs. Retrieved from https://www.iea.org/reports/ccus-in-clean-energy-transitions

[3] Global CCS Institute. (2024). *Global status of CCS 2024*. Global CCS Institute. Retrieved from https://www.globalccsinstitute.com/publications/global-status-of-ccs-2024/

[4] Du, C., Tang, J., Wang, Q., Sun, Y., Guo, J., & Wu, L. (2025). Development status and international experience of carbon capture and storage. *China Mining Magazine, 34*(9), 15–30.

DOI: 10.54254/2753-7064/2026.39333

[5] Su, X., Qiu, J., Luan, L., & Mei, Y. (2025). Source–sink matching and cluster layout of carbon capture, utilization and storage in China towards carbon neutrality. *Climate Change Research, 21*(3), 373–386.
[6] Ye, Y., Liao, H., Wang, P., Wang, J., & Li, Q. (2018). Research on technology directions and roadmap of CCS/CCUS for coal-fired power generation in China. *Strategic Study of CAE, 20*(3), 80–89.
[7] Liang, X., Yu, X., Xia, C., Liu, M., & Gao, Z. (2024). Assessment of the climate benefits and economic feasibility of carbon dioxide utilization pathways. *Southern Energy Construction, 11*(5), 1–14.
[8] Mo, L., Liu, P., & Xu, M. (2024). Carbonation of steel slag and its application in producing low-carbon construction materials. *Journal of Building Materials, 27*(12), 1122–1128.
[9] Yang, Y., Zhou, J., Hu, H., Guo, C., Luo, M., Ma, J., Guo, F., & Huang, Z. (2025). Development status, economic benefits and future prospects of CCUS-EOR industry. *China Mining Magazine, 34*(2), 190–203.
[10] Zhang, Y., Xiong, X., Zhou, Y., Wei, P., & Tan, H. (2025). Research progress of CO_2 capture, utilization and storage technology. *Journal of China Coal Society, 50*(S1), 515–533.
[11] Cai, B., Li, Q., Zhang, X., et al. (2021). Annual report on carbon dioxide capture, utilization and storage (CCUS) in China (2021): China CCUS pathway study. Beijing: Chinese Academy of Environmental Planning, Chinese Academy of Sciences Institute of Rock and Soil Mechanics, and Administrative Center for China's Agenda 21. Retrieved from http://www.caep.org.cn/ywdt/zhxx/202107/t20210725_1154337.html
[12] Zhang, H. (2025). Carbon capture project of the China National Petroleum Corporation Xinjiang Oilfield 2.64 GW integrated project of new energy, supporting coal-fired power generation and carbon capture. China Petroleum News Center. Retrieved from https://www.news.cn/energy/20250523/a731865a71ce4f34bd5f97b017b7421f/c.html
[13] Xinjiang Uygur Autonomous Region Development and Reform Commission. (2023). Approval of the 2 × 660 MW integrated demonstration project combining coal-fired power generation, renewable energy, and million-ton-scale CCUS of China National Petroleum Corporation Xinjiang Oilfield Company in Karamay. Xinjiang Uygur Autonomous Region Development and Reform Commission. Retrieved from https://xjdrc.xinjiang.gov.cn/
[14] China Academy of Building Research. (2019). Standard for calculation of carbon emissions from buildings: GB/T 51366-2019. Beijing: China Architecture & Building Press. Retrieved from https://www.mohurd.gov.cn/gongkai/zc/wjk/art/2019/art_17339_240723.html
[15] Wu, Z., Huang, H., Chen, X., et al. (2023). Countermeasures for low-carbon transformation of the construction industry in China toward the carbon peaking and carbon neutrality goals. *Strategic Study of CAE, 25*(5), 202–209.