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Comparative Analysis of CCS Full-Process Technology and Multi-Industry Application

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Abstract. Carbon capture and storage (CCS) is widely regarded as one of the key technologies for helping energy-intensive industries overcome decarbonisation challenges and achieve carbon neutrality. The existing research has largely focused on individual aspects of CCS technology or a single industry, and there is a lack of systematic, end-to-end, cross-industry comparative analysis. This research focuses on three major energy-intensive industries—thermal power, cement, and steel—and also examines bioenergy with carbon capture and storage (BECCS) as a negative-emission technology. Based on a review of the relevant literature, this paper examines the complete CCS chain, including carbon capture, transport, and storage. It conducts a multidimensional comparison of the suitability, application characteristics, and developmental limitations of CCS technology across these industries. This research indicates that significant differences exist in the production processes and carbon emission mechanisms among these industries, and that no single CCS pathway is suitable for all industries.: Thermal power generation offers the most favourable conditions for large-scale deployment; the cement industry faces a pressing need for decarbonisation; the steel industry is better suited to capturing carbon from multiple dispersed emission sources; and BECCS can achieve negative emissions and make up for the gap in industrial residual emission reduction. The research has clarified the differentiated development pathways of CCS in various industries, providing a theoretical framework for the industrialisation of CCS and the low-carbon transition in energy-intensive industries.

Keywords: CCS, BECCS, Energy-intensive industries, Decarbonisation

1. Introduction

1.1. Background and context

According to the Sixth Assessment Report of the IPCC, human activities have been the primary driver of rising temperatures, resulting in the global average surface temperature from 2011 to 2020 being 1.1 °C above pre-industrial levels [1]. Since the Industrial Revolution, fossil fuel combustion has been the primary contributor to the continuous increase in atmospheric CO_2 concentrations and the intensification of global warming. Conventional mitigation measures, such as energy substitution

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and electrification, are insufficient to address all decarbonisation challenges. Cement production generates unavoidable process-related CO_2 emissions, steelmaking relies on high-temperature production processes, and thermal power generation must continue to ensure a stable electricity supply during the energy transition.; and thermal power still needs to ensure the stable supply of electricity during the transition period of energy transformation. Achieving global carbon reduction targets by 2050 is widely considered to require the deployment of CCS technologies, a view shared by the International Energy Agency (IEA) and many other international organisations [2]. Carbon capture and storage (CCS) technology was first proposed in 1977, which first achieves the separation of CO_2 with the help of the capture link, and then through purification and transhipment, and finally completes the sequestration of CO2 [3]. In the early days, CCS was used solely as a supporting emission reduction technology for fossil fuels. In recent years, CCS has attracted renewed attention owing to the implementation of national net-zero strategies, increasing decarbonisation demands in hard-to-abate sectors such as cement, steel, and thermal power generation, as well as the negative-emission potential of bioenergy with carbon capture and storage (BECCS). As the global transition towards deep decarbonisation continues to advance, CCS has evolved from a supporting technology for fossil fuels into a core enabling technology for hard-to-abate industries to achieve net-zero emissions. Therefore, it is necessary to systematically summarise the whole-process CCS technology and its application characteristics across typical industries.

1.2. Research problem or question

Most existing studies on CCS focus either on a single industry or on a specific stage of the CCS process, such as carbon capture, transport, or storage. Similarly, existing review articles mainly summarise technological developments within individual industries, while systematic cross-industry comparisons covering the entire CCS value chain remain limited.

The production conditions of thermal power, steel, cement and other industries are different, and there are also significant gaps in terms of the energy consumption involved in carbon capture, gas conditions, storage, transport and sequestration requirements, and application costs. At present, there is still a lack of a complete CCS technical system based on the unified comparison of the application differences between the above-mentioned industrial fields and BECCS paths, and there is a lack of a systematic summary of the technical adaptation characteristics and development directions of each industry. This paper will provide a comparative analysis of the characteristics of CCS adoption and prospects across various industries.

1.3. Objectives of the study

This research reviews technological advances across the entire CCS value chain, analyses the characteristics of CCS applications in different industries, compares the suitability, advantages and limitations of CCS technology pathways across various industrial industries, and discusses existing challenges and future trends, thereby providing a basis for the decarbonisation of energy-intensive industries.

1.4. Significance of the study

This research defines the scope of application of various CCS technologies and builds a multi-industry CCS comparison framework; at the same time, it clarifies the differentiated development

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path of each industry and provides reference for energy-intensive industries to plan CCS layout and promote technology industrialisation.

1.5. Overview of the paper structure

The paper begins by introducing the research background, followed by an overview of the complete CCS technology chain, including carbon capture, transport, and storage. It then reviews the application of CCS across different industries, highlighting their technological characteristics, practical progress, and key challenges. Finally, the paper summarises the future prospects of CCS and discusses potential directions for its industrial deployment based on the application characteristics and development needs of different industries.

2. Literature review

2.1. Overview of the existing research

The existing CCS research is mainly divided into three categorised : Firstly, CCS whole industry chain technology research, which compares various capture, transport and geological storage options, with a focus on analysing technical bottlenecks such as the high energy consumption associated with capturing low-concentration flue gas and leakage during storage [2]; Secondly, a study assessing the economic environment calculated the overall benefits of CCS within carbon neutrality pathways from an energy system perspective [4]. The study indicates that although CCS can reduce the overall cost of decarbonisation, its deployment may also introduce additional environmental burdens, including increased energy and resource consumption. It further examines the application of CCS in energy-intensive industries such as cement, steel, and thermal power generation, and discusses potential pathways for large-scale implementation. In addition, Europe and the United States have established large-scale CCS industrial clusters supported by relatively mature monitoring systems. Although several large-scale CCS demonstration projects have been launched in China, further improvements are still needed in permanent storage infrastructure and long-term monitoring systems.

2.2. Identification of gaps in the literature

The existing research is largely confined to individual technical aspects or single energy-intensive industries, and a universal, cross-industryal evaluation framework has yet to be established. There are very few studies that cover the entire CCS process chain and conduct a comparative analysis of the process suitability, energy consumption and technical differences between thermal power, steel, cement and BECCS; as a result, there is a lack of systematic summarisation of emission reduction schemes across these industries, making it difficult to support the coordinated planning of multi-industry integrated CCS.

2.3. Relevance to the current study

Existing studies have systematically reviewed the applications, technical advantages and limitations, and demonstration projects of CCS in the cement, steel, thermal power, and bioenergy with carbon capture and storage (BECCS) sectors, providing a solid foundation for understanding the development status and key challenges of each industry. Building on these findings, this review establishes a unified framework for cross-industry comparison to evaluate the application

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characteristics of CCS from multiple perspectives. By comparing different industries within a consistent analytical framework, the review summarises the common features and industry-specific requirements of CCS deployment, thereby addressing the limited systematic cross-industry comparisons in previous studies.

3. Methology

3.1. Research design

This paper uses Google Scholar as the search platform, with the search period covering mainly the years 2020 to 2026. The keywords used were 'CCS technology', 'CCS in the thermal power, cement and steel industries' and 'BECCS'. The literatures was ranked by relevance, with priority given to publications from the last five years. Preliminary retrieval of 67 literatures; inclusion criteria: journal papers and authoritative industry reports focusing on CCS technology, industrial applications, development and BECCS; exclusion criteria: duplicate literatures and content unrelated to the topic. Following screening and a thorough review, 32 papers were ultimately included; based on these, the current status of CCS applications across various industries and the latest research developments were summarised.

4. Results

4.1. CCS end-to-end technical analysis

4.1.1. Carbon capture technologies

For exhaust gases generated by industrial production, the capture stage enables the separation of CO_2 from other gases [5]. According to different process principles, there are three main approaches to CO_2 capture: pre-combustion capture, post-combustion capture and oxy-combustion capture [6]. The three types of technology have differences in capture efficiency, operating costs and suitability for specific operating conditions, and have now given rise to a diversified landscape of industrial applications.

Post-combustion capture is applied at the end of the production process and treats flue gas generated from fossil fuel combustion. During the capture process, CO_2 is separated from the exhaust stream, while impurities such as water vapour, sulphur oxides, and nitrogen oxides are also removed [7]. Although this technology generally has a higher energy penalty than some alternative capture routes, its mature process design and compatibility with existing facilities make it economically attractive in many applications [5]. Owing to these advantages, post-combustion capture has been widely deployed in the power sector and is increasingly being applied in hard-to-abate industries, such as cement production, where deep decarbonisation remains a significant challenge. Overall, the biggest advantage of this technology is its compatibility with existing industrial units and the low level of retrofitting required; as a result, it has become the mainstream capture technology of choice for coal-fired power stations and the cement industry.

Pre-combustion capture enables the separation of CO_2 before fuel combustion and simultaneously produces hydrogen as a clean energy carrier, with water as the primary product of hydrogen combustion [8]. This technology generally achieves higher CO_2 capture efficiency than post-combustion capture, but it also requires more complex process modifications and higher capital investment [5]. Compared with post-combustion capture, pre-combustion systems offer greater

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potential for improving overall energy efficiency, making them a promising option for future low-carbon energy systems [7]. At present, this technology is mainly applied in process-intensive industries, such as coal gasification, hydrogen production, and coal chemical processes, where fuel pre-treatment is already integrated into the production system. In contrast, its application in conventional industries such as thermal power generation and cement production remains limited because of the relatively simple process configurations and the high cost of retrofitting existing facilities.

Oxy-combustion involves using high-concentration oxygen in place of air for the combustion of fossil fuels [7]. The total cost of ownership for this technology is relatively low [5]. Existing research shows that this technology is mature and suitable for application in the metallurgical and coal-fired power industries; but throughout the whole industry, the level of investment and enthusiasm for implementing this technology remains relatively low in most areas [9]. As this technology is suited to high-temperature, high-concentration carbon emissions conditions, the steel and metallurgy industries have largely prioritised pilot schemes for Oxy-combustion capture technology; but its universality is weaker than that of post-combustion capture, and the scope of popularisation is relatively limited.

Overall, the three types of carbon capture technologies each have their own advantages and disadvantages in Table 1 : post-combustion capture is highly mature and versatile, and is currently the mainstream technology in the civil industry at this stage; the pre-combustion capture efficiency and energy performance are execlllent, but is subject to significant cost constraints; Oxy-combustion offers the highest capture efficiency and is relatively cost-effective, but its applicability within the industry is limited. The three have formed a technological development framework of 'general terminal management+high-end energy-saving capture+high-efficiency special capture'.

Table 1. Comparison of three trapping techniques

Technology Type	Cost and Energy Consumption	Core Industries	Key Advantages	Current Limitations
Post-combustion capture	Excellent efficiency Relatively High energy consumption	Traditional existing industries such as thermal power generation and cement	Proven technology Easy to retrofit Compatible with existing equipment	Poor capture efficiency Limited scope for emissions reductions within the industry Some processes have relatively high energy consumption
Pre-combustion capture	High initial investment Significant energy-saving benefits Excellent long-term economic returns	Process industries such as coal chemical production, coal-based hydrogen production and chemical synthesis	High capture efficiency, low energy consumption No secondary pollution	Complex manufacturing processes and high retrofitting costs Not compatible with older equipment
Oxy-combustion capture	Low operating costs Effective energy consumption management	High-carbon-emission sectors such as metallurgy and thermal power generation	High capture efficiency, low cost Suitable for high-concentration flue gas applications	Limited scope of application Low level of willingness among traditional industries Low level of industrialisation

4.1.2. Carbon transport technologies

Once CO_2 has been captured, separated and processed, it can be transported to designated storage sites via a variety of routes. In terms of the application situation at this stage, CO_2 is primarily transported via pipelines or by ship, and the operational conditions suited to each mode of transport differ.

Pre-combustion capture separates CO_2 before fuel combustion while producing hydrogen as a low-carbon energy carrier, with water being the main product of hydrogen combustion [8]. Compared with post-combustion capture, this technology generally achieves higher CO_2 capture efficiency and offers greater potential for improving overall energy efficiency, although it requires more complex process integration and higher investment costs [5, 7]. Pre-combustion capture is therefore better suited to industries that already incorporate fuel pre-treatment processes, such as coal gasification, hydrogen production, and coal chemical production. By contrast, its application in conventional sectors, including thermal power generation and cement production, remains limited because substantial modifications to existing production systems are required.

Overall, the transport stage plays a key role in the carbon capture and storage (CCS) industry chain, with pipelines and ships being the primary ways to undertake the transhipment of CO_2. Although existing technology is developing and improving, there is still room for process optimisation, and deeper research is required into areas such as the impact of impurities and the hazards of gas leaks [9-10]. The industry has now established a transport system characterised by 'mainly short-distance pipelines, supplemented by long-distance ships; the overall technology is stable, but the subdivision, safety and refinement technology still require further improvement.

4.1.3. Carbon storage technologies

After CO_2 capture, purification, and compression, the captured CO_2 needs to be transported to designated locations for long-term storage [11]. Currently, CO_2 storage methods are mainly classified into two categories: geological storage and ocean storage. Geological storage mainly includes storage in oil and gas reservoirs and deep saline aquifers. Depleted oil and gas reservoirs possess complex geological structures, sufficient storage space, and favourable sealing conditions. In addition, existing surface and subsurface infrastructure can often be reused with limited modifications, making them suitable for CO_2 storage applications [9]. The long-term retention of oil and gas resources within these formations over geological timescales also provides evidence of their potential for stable CO_2 containment [12]. Another important geological storage option is deep saline aquifers. These formations are widely distributed worldwide and generally have large storage capacities, making them one of the most promising options for long-term CO_2 storage [12]. Compared with other storage methods, saline aquifer storage combines extensive geographical availability, considerable storage potential, and relatively low operational costs, and is therefore considered a key pathway for future carbon sequestration [10]. In comparison with geological storage, ocean storage may appear to provide a larger storage capacity; however, it still faces significant environmental concerns. Injected CO_2 can dissolve in seawater, potentially altering local carbon concentrations and reducing seawater pH. In addition, the migration and dispersion of dissolved CO_2 may affect marine ecosystems, with potential impacts becoming more significant as the scale of CO_2 injection increases [10].

Overall, geological storage is currently the core mainstream technology for carbon storage; whilst depleted oil and gas fields are suitable for short-term, large-scale transformation applications, and the seawater aquifer has the absolute potential for long-trem and large-scale; Ocean storage is

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constrained by ecological risks; at present, it remains at the stage of theoretical research and small-scale pilot projects, and the conditions for large-scale industrialisation are not yet in place.

4.2. The thermal power industry

With its stable cost advantage, coal has long occupied a significant position in the global energy system and is unlikely to be completely replaced in the short term. The thermal power sector has the characteristics of concentrated CO_2 emissions sources, high total emissions, and a large number of existing large-scale power-generating units; CO_2 emission levels from fossil fuel-fired power generation facilities are influenced by a combination of factors, including fuel type, power generation processes, installed capacity, and energy conversion efficiency [7].

Carbon capture and storage (CCS) and renewable energy (RE) technologies are two key pathways for reducing CO_2 emissions in the electricity sector. Flue gas emissions from coal-fired power generation units are characterised by high temperatures and low partial pressures of CO_2; at present, the mainstream decarbonisation methods include physical absorption, chemical absorption and membrane separation; The vast majority of carbon capture projects at coal-fired power stations in China utilise chemical absorption technology, with individual enterprises independently formulating their own distinctive alcohol-amine absorption liquid systems; however, absorption media such as alcohol-amines and ammonia water generally suffer from inherent shortcomings, including relatively high energy consumption during regeneration and complex process flows [13]. Process routes that integrate the CO_2 separation stage into the integrated design of power generation systems can minimise capture costs; The energy efficiency loss of this kind of process power generation is relatively small. At the same time, there is no need to carry out supporting infrastructure investment for generator sets and carbon capture units separately. Owing to its stable cost advantage, coal has long occupied a significant position in the global energy system and is unlikely to be completely replaced in the short term; this has resulted in the thermal power sector having a high baseline of carbon emissions and facing significant pressure to transition to low-carbon practices [14].

To date, leading state-owned energy enterprises in China, such as Huaneng, State Power Investment Corporation and Datang, have completed several 100,000- to 1,000,000-metric-tonne-scale CCS demonstration projects for thermal power generation. The captured CO_2 is primarily used for enhanced oil recovery or deep geological storage, which, whilst ensuring the stable operation of the power system, effectively reduces the carbon emission intensity of existing thermal power units and supports the low-carbon transition of the thermal power sector. Therefore, at present, the thermal power industry has become the most commercialised application field of CCS.

4.3. The cement industry

As a basic pillar industry characterised by significant resistance to carbon emission reductions, the cement industry has it own irreversible carbon emissions in the processes, and ranks among the industries with the greatest overall resistance to emission reductions worldwide [15]. Carbon emissions from cement production are divided into two categories: raw material calcination emissions and fuel combustion emissions. Process emissions resulting from the high-temperature decomposition of limestone account for 60 % of total emissions, whilst emissions from coal-fired kiln heating account for the remaining 40 % [16]. This also means that deep decarbonisation of the cement industry cannot be achieved without CCS technology. Emissions from fuel combustion can be reduced through the use of clean energy alternatives and energy-saving retrofits; however, the

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higher proportion of limestone decomposition emissions is an irreversible process emission inherent in production, which is difficult to avoid. Traditional energy-saving measures alone are insufficient to achieve full decarbonisation in the cement industry, making decarbonisation more challenging than in most other industrial sectors. The process flows of cement production lines are highly standardised; the flue gas from the kiln contains CO_2 from two sources—raw material decomposition and fuel combustion—and the volume fraction of CO_2 in the flue gas is significantly higher than that in coal-fired power plants. Whilst this provides certain inherent conditions for carbon capture, there are also numerous practical limitations [15]. At present, the mainstream of the cement industry choose the post-combustion, post-capture solutions; this technology has a large investment in infrastructure and entails relatively high operating costs for companies; At the same time, the adsorbent medium used in this technology is easily eroded, necessitating the installation of additional pre-treatment facilities to remove sulphur and nitrogen oxides as well as solid particulates; In addition, Oxy-combustion is also a key area of research and development in the cement industry. It is divided into two modes: local oxygen supply and full-process oxygen supply. Local oxygen supply involves supplying oxygen only to the pre-decomposition kiln, with a capture efficiency of approximately 60 per cent, whilst full-process oxygen supply across the entire kiln system can achieve a capture efficiency of 85–90 per cent [14].

Several cement CCS demonstration projects have been developed in both China and other countries. China United Cement has carried out pilot-scale trials of oxy-combustion carbon capture in cement kiln systems, exploring the feasibility of applying CCS in cement production. The Norwegian Longship project has established an integrated CCS value chain that combines cement flue gas CO_2 capture, marine transportation, and geological storage. The International Energy Agency (IEA) has identified CCS as an important pathway for the low-carbon transition of the cement industry and has highlighted its potential for large-scale deployment in the coming decades. According to IEA projections, CCS deployment in the cement sector could enable annual CO_2 storage of approximately 920 million tonnes by 2050 [14].

Overall, at this stage, the cement industry continues to focus primarily on pilot projects for the development of post-combustion capture and Oxy-combustion technologies, with relatively few large-scale commercial projects; The future development direction of the industry is to optimise the flue gas pretreatment system and reduce the capture energy consumption and operating costs. On the other hand, continuously refining full-process Oxy-combustion technology, whilst simultaneously improving the supporting systems for carbon transport and storage upstream and downstream, thereby gradually increasing the scale of CCS application in the cement industry.

4.4. The steel industry

The steel industry is a fundamental manufacturing sector characterised by high energy consumption and substantial carbon emissions. Its production processes require large amounts of coal, electricity, and water, while continuously generating pollutants such as CO_2 and particulate matter [17]. As one of the major industrial emission sources, the steel sector faces significant challenges in achieving deep decarbonisation. Although measures such as energy efficiency improvements and electrification can reduce emissions to some extent, they alone are insufficient to achieve long-term carbon reduction targets. Compared with the relatively concentrated and stable emission sources in the thermal power sector, carbon sources in the steel industry are more diverse and distributed across different production processes, making CCS deployment more technically challenging. Current research and engineering applications of CO_2 capture in the steel industry mainly focus on blast furnace gas, with liquid-phase amine absorption and solid-phase adsorption being the two

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commonly investigated approaches. Since blast furnace gas contributes more than 70% of the total CO_2 emissions from steel production, it represents the primary target for carbon capture applications in this sector [18]. At present, the steel industry mainly applies post-combustion capture and oxy-combustion technologies to recover CO_2 from blast furnace top gas and other process off-gases [17].

The traditional long-process steelmaking method, involving blast furnaces and converters, cannot be completely phased out in the short term. The potential for emissions reductions through energy-saving retrofits and adjustments to raw materials has nearly reached its limit; however, the installation of CCS equipment can capture carbon emissions that cannot be reduced during the process, thereby continuing to lower the carbon emissions levels of long-process production lines. China's two major steel groups, Baowu and Hebei Iron & Steel, have both established demonstration projects for CCS systems integrated with blast furnaces. These projects are designed to cope with the highly variable and complex operating conditions of blast furnaces, thereby providing concrete evidence of the practical value of CCS technology in the low-carbon transformation of the steel industry. Overall, CCS in the steel industry is currently only in the small-scale demonstration stage and has not yet been commercialised on a large scale; In the future, the application gap with the thermal power industry can be narrowed by improving adsorption materials, improving oxygen-enriched combustion technology, and optimising the cooperative capture technology of dispersed gas sources.

4.5. BECCS technology

Bioenergy with Carbon Capture and Storage (BECCS, also known as Bio-CCS) is a sub-branch of the carbon capture and storage technology framework; the only difference between the two technologies lies in the source of CO_2 [19]. Low-carbon hydrogen is the core carrier in the transition process of the whole society to net-zero emissions by 2050. This technological system not only produces low-carbon hydrogen but also achieves CO_2 negative removal (CDR), and such negative carbon removal technology is also an indispensable and important way to neutralise the difficulty of reducing residual carbon emissions in various industries [20]. BECCS fixes atmospheric carbon dioxide through biomass growth, then uses biomass combustion to provide energy, and captures and seals the carbon dioxide generated by combustion. When the amount of carbon sealed offsets the carbon emissions of the whole process, the system can achieve negative emissions, thereby reducing atmospheric CO_2 concentrations. Carbon capture and storage (CCS) technology can be applied to the carbon emission control scenarios of commodity pulp production lines and comprehensive pulp and paper enterprises; the feasibility of its implementation in this sector is broadly on a par with that of carbon capture applications in other industrial sectors [19]. As the pulp and paper industry makes extensive use of biomass energy, it has become a key application area for BECCS. The pulp and paper industry is characterised by high energy consumption and a significant share of biomass energy; renewable energy substitution is an important means of carbon reduction, but it is difficult to achieve deep decarbonisation by relying on fuel substitution alone; it is also necessary to promote technological upgrades and phase out outdated production capacity to improve energy efficiency. Sulphate-process pulp mills have a low baseline for fossil carbon emissions; even if the carbon capture efficiency is limited, it can still form a carbon sink effect. At the same time, the pulp and paper manufacturing process generates a large amount of low-temperature waste heat, the utilisation rate of which is currently relatively low. It is possible not only to improve energy efficiency, but also to create favourable conditions for the supporting BECCS technology in the factory.

Several BECCS demonstration projects have been developed in Europe and the United States, particularly in the pulp and paper industry, where solid adsorption technologies are applied to

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capture CO_2 from biomass combustion flue gas before geological storage. Compared with conventional industrial CCS technologies, BECCS provides additional negative-emission benefits by not only reducing carbon emissions from the paper industry itself but also compensating for residual emissions that are difficult to eliminate in other sectors. Therefore, BECCS is considered an important component of broader carbon neutrality strategies and has significant potential in future decarbonisation pathways.

5. Conclusion

This research systematically reviews the full-process CCS technology framework and compares the application scenarios and technical characteristics of CCS across three major energy-intensive sectors, including thermal power, cement, and steel. By incorporating the negative-emission potential of BECCS, this review analyses the differentiated suitability of CCS deployment across various sectors, addressing the limitations of previous studies that mainly focused on individual industries and lacked comprehensive cross-sector comparisons.

The review indicates that differences in production processes, flue gas characteristics, and carbon emission mechanisms result in the absence of a universal CCS pathway for all energy-intensive industries. Instead, sector-specific deployment strategies are required. In the cement industry, unavoidable process-related CO_2 emissions from limestone decomposition create a strong demand for CCS-based emission reduction. The thermal power sector benefits from relatively concentrated emission sources and extensive demonstration experience, providing favourable conditions for large-scale CCS deployment, although high energy consumption during the capture process remains a major challenge. In the steel industry, dispersed emission sources and complex operating conditions limit the independent application of CCS, making it more suitable as a complementary technology combined with process optimisation. Meanwhile, BECCS provides negative-emission potential and can contribute to offsetting residual emissions that are difficult to eliminate in industrial sectors.

Based on the cross-industry comparison, this paper suggests that the future development of CCS should avoid a uniform deployment strategy and instead adopt targeted approaches according to the characteristics and challenges of different industries. For the cement sector, priority should be given to process-related emission capture; for thermal power generation, the focus should be on improving capture efficiency and reducing energy consumption; for the steel industry, further development of capture technologies suitable for dispersed emission sources is needed; and the integration of conventional CCS with BECCS should be promoted to enhance overall carbon reduction potential. Overall, CCS represents an important pathway for achieving deep decarbonisation in energy-intensive industries. Due to differences in emission sources, flue gas composition, and production processes, future CCS deployment should follow differentiated strategies rather than a single technical route, which will support the large-scale and sustainable development of CCS technologies.

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