

Cost Analysis and Future Prospects of BECCS Deployment in China[#]

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ABSTRACT

Bioenergy could offer zero-emission high-temperature heat and fuels that work in existing engines and industrial infrastructure, and bioenergy with carbon capture and storage (BECCS) stands out as a crucial negative emission technology (NET) essential for achieving carbon neutrality. This study examines the carbon removal cost of biomass-fuelled power plants with CCS (BFP-CCS) and bioethanol plants with CCS (BP-CCS), revealing current carbon removal cost ranges of \$88 to \$288 /t CO₂ and \$20 to \$175 /t CO₂, respectively. The paper makes predictions about the scale of BECCS in two scenarios, radical and conservative. Utilizing the learning curve approach, the study predicts cost reductions from 64.6% to 92.1% for BFP-CCS and BP-CCS by 2100. Furthermore, the potential scale of BECCS applications is estimated to reach 2 billion tonnes per year, highlighting its cost-effectiveness, particularly in comparison to the projected costs of direct air carbon capture. However, the lack of targeted policy support for carbon capture and storage technologies in China, in contrast to other clean energy technologies, represents a significant hurdle. Enacting comparable policy incentives can foster the commercialization and large-scale deployment of BECCS, thereby accelerating the carbon neutrality progress of China 2060.

Keywords: BECCS, carbon neutrality, economic analysis, learning curve, cost prediction

NONMENCLATURE

Abbreviations

BECCS	Bioenergy with carbon capture and storage
NET	Negative emission technology
CCS	Carbon capture and storage
BFP-CCS	Biomass-fuelled power plants with CCS
BP-CCS	Bioethanol plants with CCS

Symbols

t	Tonne
Lr	Learning rate
b	Learning index
y	Carbon removal cost of current scale after scale-up
α	Carbon removal cost of the first BECCS project
x	the ratio of future scale to initial scale

1. INTRODUCTION

Bioenergy is a zero-emission energy source that is critical for industry, heat production. Bioenergy with carbon capture and storage (BECCS) stands out as a crucial negative emission technology (NET) essential for achieving carbon neutrality^[1]. A schematic of the BECCS is shown in Fig. 1. Initially, plants play a pivotal role in sequestering carbon dioxide from the atmosphere. Subsequently, crop waste is sent to biomass-fired power plants to be burned for electricity, and corn is sent to bioethanol plants to be fermented into alcohol. Finally, the resultant carbon dioxide emissions undergo capture and storage, thereby facilitating the realization of negative emissions throughout the process, thus contributing to the promotion of carbon neutrality.

The future market for BECCS in China is promising. According to the 3060 Blue Book on Zero Carbon Biomass Potential, it is estimated that by 2030, China will have achieved more than 900 million tonnes of carbon reductions through the use of BECCS, and more than 2 billion tonnes of carbon reductions by 2060^[2]. Furthermore, some studies have indicated that the maximum annual emission reduction potential of China's BECCS technology could reach up to 5 billion tonnes of CO₂, contributing to a total economic scale of nearly US\$914 billion^[2].

Many studies on techno-economic analysis of BECCS have emerged in recent years. Fan et al.^[3] analysed that the current consolidated carbon removal cost of the BFP-CCS project is \$88~288/t CO₂, while the

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BP-CCS project is \$20~175/t CO₂. Hasegawa et al.^[4] analysed that large scale deployment of BECCS will have a significant impact on land resources and food prices. Fajardy et al.^[5] utilised the Economic Projection and Policy Analysis model (EPPA) analysis to derive the BECCS sustainability when the carbon price is \$240/t CO₂

While China's BECCS holds significant developmental promise, the actual implementation of projects on the ground remains scarce, primarily due to apprehensions surrounding its substantial construction

costs. However, research on the cost of BECCS in China is still relatively limited. This study employs the fitted curve to predict the future potential of BECCS development and application scale. Then the technology learning curve is utilized to predict how the future cost of BECCS application decreases. These predictions can provide a reference for the enterprises and the state to invest in the construction of BECCS projects.

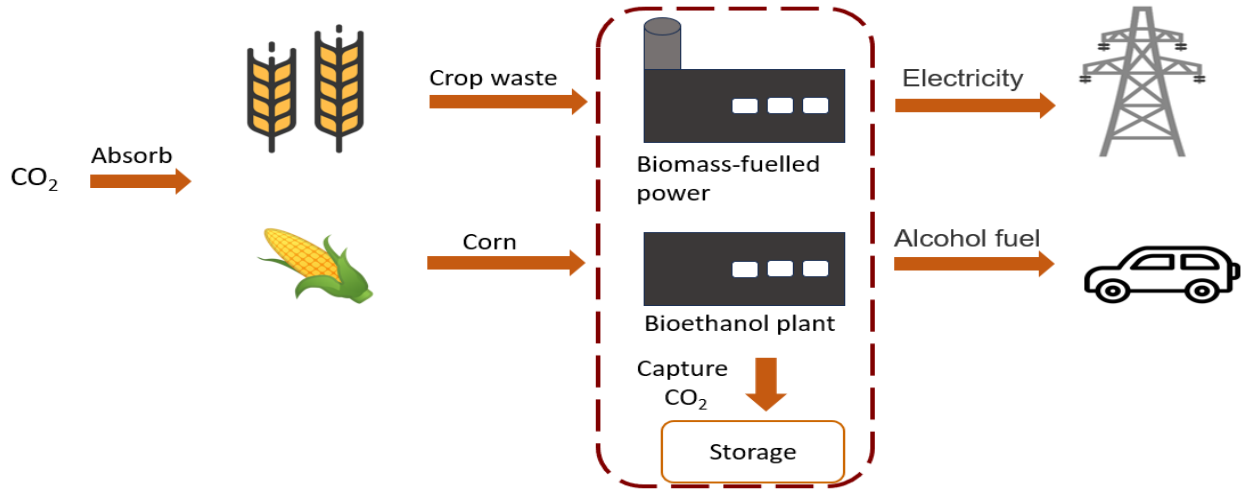


Fig. 1 Schematic of the BECCS

2. METHODS

2.1 Deployment model

This study divides the scale of BECCS deployments into radical and conservative scenarios. The radical scenario predicts a strong development of BECCS as a key technology in China to achieve its carbon neutrality goal. Conservative scenarios indicate that BECCS is less developed than expected in China. The radical scenario assumes that the deployment speed is a power function of time, whereas the conservative scenario follows an S-curve fitting of time, which is divided into three time periods: slow deployment, accelerated deployment, and high-speed deployment. After carbon neutrality is achieved in 2060, the deployment scale of BECCS tends to stabilize.

2.2 Technology learning curve

The technology learning curve is a reflection of the law that the cost of technology declines as it is accumulated and applied on a larger scale^[6]. As depicted in Fig. 2, when a technology is initially applied, costs tend to be comparatively high. Subsequently, the technology undergoes a phase of rapid development, resulting in a significant reduction in costs. Eventually, as the

technology matures, costs stabilize. The relevant formulas are as follows:

$$b = -\frac{\ln(1-Lr)}{\ln 2} \quad (1)$$

$$y = \alpha \cdot x^{-b} \quad (2)$$

Where b is learning index, Lr is learning rate, y is carbon removal cost of current scale after scale-up. α is carbon removal cost of the first BECCS project. x is the ratio of future scale to initial scale. The learning rate is the most important parameter in a technology learning model. A higher learning rate can make the cost decrease significantly to an acceptable range, even if the initial cost is very expensive^[7].

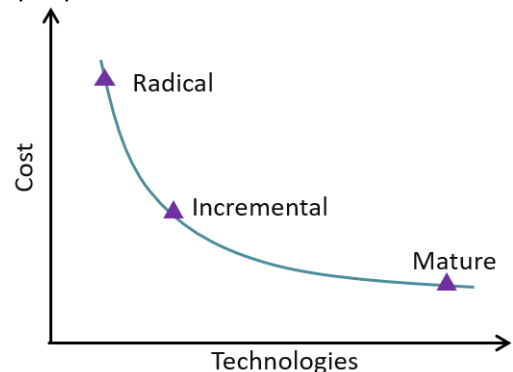


Fig. 2 Technology learning curve Schematic diagram

2.3 Case setting

The conditions and maturity of the different CCS technologies vary, and the existing CCS technologies, which are mostly used in the chemical industry, may differ when they are transferred to bioenergy applications. Therefore, the selection of a suitable capture technology is based on the physical properties of the flue gas. Table. 1 collects the key parameters of some current mainstream CCS technologies, and Table. 2 presents the parameters of the two biomass technologies promoted by China. According to the 14th

Table. 1 Key parameters of common CCS technologies

CCS	Temperature (°C)	CO ₂ %	Matching plant scale	Cost (\$/t)
Physical Sorbents (PSA/ TSA) ^[10]	35~128	>33%	Small	60
Chemical Sorbents (MEA) ^[11]	30~45	>10%	Small	80
Membrane Separation	~	>50%	Large	High
Chemical Looping ^[12]	1150	>50%	1000MW	58
Calcium Looping ^[13]	900	15%~95%	3kW~1.9MW	56

Table. 2 Parameters of flue gas emitted by BFP and BP

	BFP	BP
CO ₂ %	12-14 ^[14]	30-40
Exhaust temperature (K)	321	260
Main biomass	Crop waste	Corn

3. RESULTS

3.1 BECCS deployment prediction

The data from Table. 3 are processed by computing the mean values. Subsequently, an S-curve fitting analysis is conducted based on the existing data to project the future BECCS emission reduction potential up to the year 2100. Using the same methodology, the data in Table. 4 are fitted with a power function to predict the scale of BECCS by 2100.

Table. 3 A conservative prediction of BECCS emission reduction potential from 2025 to 2060^[15]

Year	Scale (million tonnes/year)
2025	0.5
2030	1
2035	18
2040	80~100
2050	200~500
2060	300~600

Five-year plan for renewable energy development, China has a large amount of waste straw and a large yield of corn, making BFP and BP technologies the most suitable bioenergy technologies for China's development, it is assumed that BFP-CCS will constitute 60% of BECCS deployment, while BP-CCS will comprise 40%^[8]. Therefore, this study sets out to study the BFP-CCS and BP-CCS. At the same time, the learning rate was set to 0.1, 0.15 and 0.2 for low, medium and high learning rates respectively, as referenced in the study by Kang et al^[9]. Higher learning rates indicate more ideal technological development and more significant cost reductions.

Table. 4 A radical estimate of BECCS emission reduction potential^[2]

Year	Scale (million tonnes/year)
2025	0.5
2030	900
2060	2000

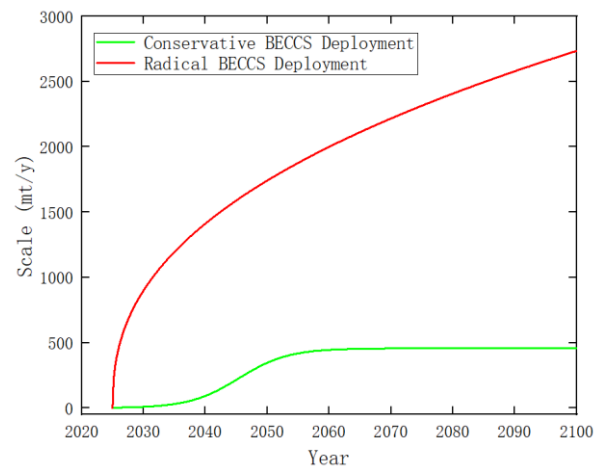


Fig. 3 Conservative and radical BECCS Deployment Fitting Curve Predictions from 2025 to 2100

As illustrated in Fig. 3, in the radical scenario, the scale exhibits growth following a power function, ultimately reaching 2743 MtCO₂/y. Conversely, in a conservative scenario, the scale increases modestly before plateauing, stabilizing at 459 MtCO₂/y.

Consequently, these dynamics result in a six-fold difference between them.

3.2 BECCS future cost predictions

The initial consolidated carbon removal cost of the BFP-CCS project is estimated at \$88~288/t CO₂, whereas for the BP-CCS project, it ranges from \$20~175/t CO₂. To facilitate subsequent studies, averaging is performed. Set the initial consolidated carbon removal cost of the BFP-CCS to \$188/t CO₂ and the initial cost of BP-CCS to \$98/t CO₂.

As depicted in the Fig. 4, the initial cost for BP-CCS is \$98/t. In radical scenario, costs are reduced to \$29.4/t ~ \$7.7/t, whereas in conservative scenario, costs are lowered to \$34.7/t ~ \$10.8/t. Similarly, as illustrated in the Fig. 5, the initial cost for BFP-CCS is \$188/t. In radical scenario, costs have reduced by 70.2% to 92.1%, resulting in a range of \$56.9/t ~ \$14.9/t. In conservative scenarios, the reduction ranges from 64.6% to 88.9%, bringing costs down to \$66.7/t ~ \$20.9/t.

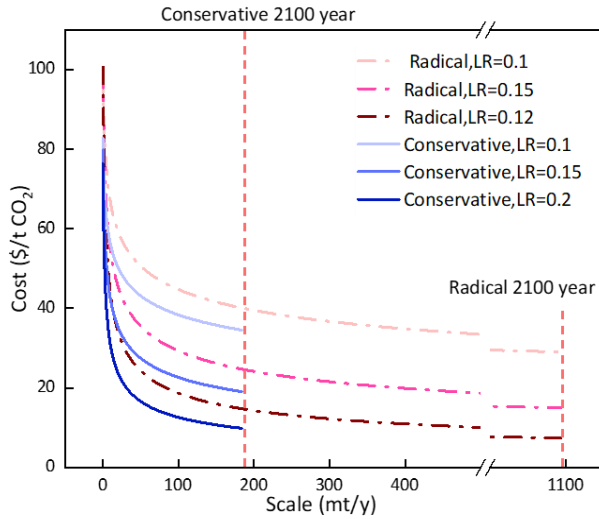


Fig. 4 BP-CCS future cost prediction

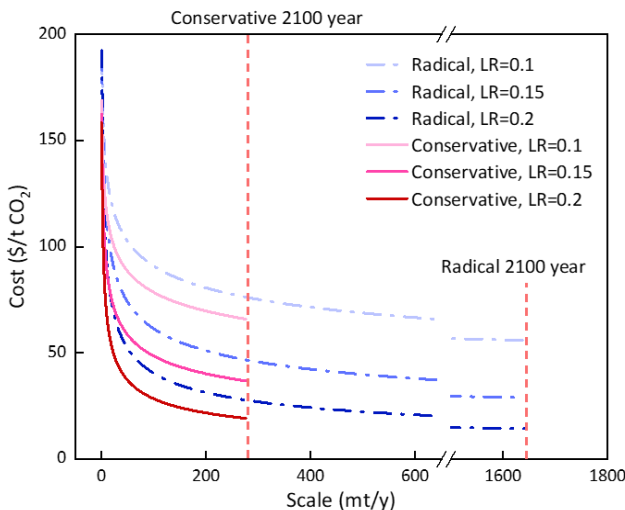


Fig. 5 BFP-CCS future cost prediction

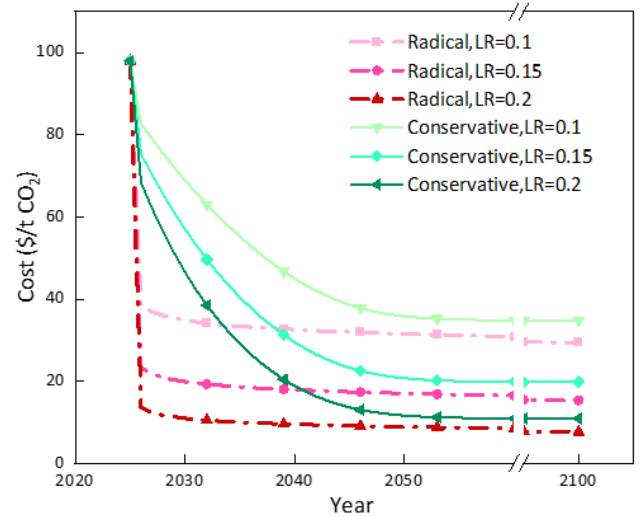


Fig. 6 BP-CCS cost trends from 2025 to 2100

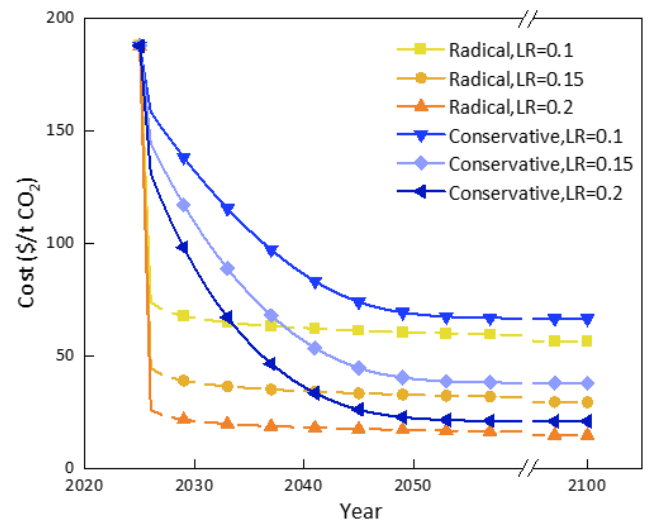


Fig. 7 BFP-CCS cost trends from 2025 to 2100

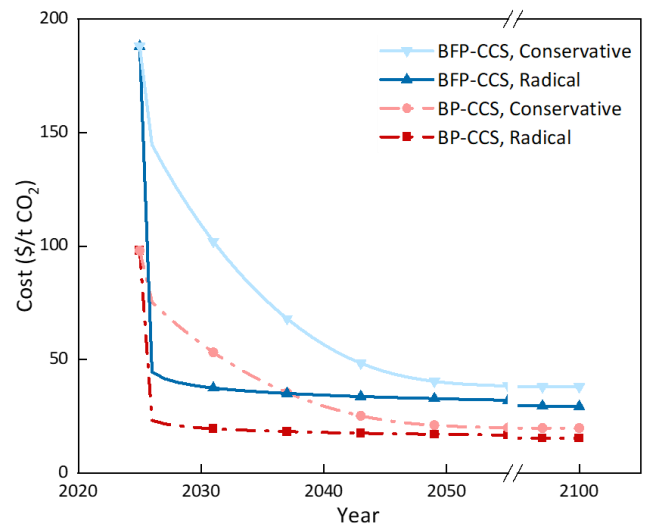


Fig. 8 LR=0.15, BFP-CCS Cost Trends Compared to BP-CCS from 2025 to 2100

Fig. 8 presents a plot derived from selected data extracted from Fig. 6 and Fig. 7. It demonstrates that Although BFP-CCS and BP-CCS start with a large difference in cost, they converge to a small difference in cost by the end of the period studied. Projected to be in the year 2100, the carbon removal cost of the BP-CCS will be \$15.1/t and \$19.2/t, while the carbon removal cost of the BFP-CCS will be \$29.4/t, and \$37.8/t. This represents a narrowing of the cost gap from nearly double the initial difference to approximately 30%.

4. DISCUSSION

The findings from the aforementioned study indicate that while there is a significant initial cost disparity among different BECCS technologies, this gap diminishes progressively as the technology develops and progresses along the learning curve. Instead, the learning rate has a greater impact on the cost. The learning rate not only reflects the pace of technology advancement but also, to some extent, the level of technological complexity. Therefore, to achieve a substantial reduction in BECCS costs, it is crucial to actively advance BECCS technology to enhance its learning rate.

This study analyses the costs associated with BECCS, providing reference and guidance for subsequent research. Future research will delve deeper into the costs associated with BP-CCS and BFP-CCS technologies to facilitate more accurate analyses. For instance, the learning rates for each technology can be calculated by examining extensive historical data. Furthermore, the emission reduction potential of BECCS could be forecasted based on the national biomass potential.

5. CONCLUSIONS

This study has evaluated the carbon removal costs of BFP-CCS and BP-CCS, and predicted the future potential for the development and application scale of BECCS. Key findings from this study include:

1). The current carbon removal costs for BFP-CCS range from \$88 to \$288 per ton of CO₂, while the carbon removal cost for BP-CCS are between \$20 and \$175 per ton of CO₂.

2). Using the learning curve approach, this study forecasts significant cost reductions in carbon removal cost, ranging from 64.6% to 92.1% by the year 2100 for both BFP-CCS and BP-CCS technologies.

3). The results indicate that although BFP-CCS and BP-CCS start with substantial cost disparities, these differences eventually narrow significantly, with the initial cost gap reducing from nearly double to approximately 30%.

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