



OPERATIONAL FLEXIBILITY OF COAL POWER PLANTS AND CARBON CAPTURE

Despite the efforts of many governments to phase out or phase down coal use, global coal power generation capacity continues to expand. Coal will remain a critical source of electricity production until 2050 or beyond, especially in Southeast Asia and parts of Africa. Therefore, decarbonising coal power generation is vital to meet CO₂ emission reduction goals. Carbon capture, with its versatility of application, demonstrated effectiveness and ability to deal with enormous volumes of emissions, is central to least-cost pathways to net zero emissions (NZE).

CARBON CAPTURE TECHNOLOGIES

There are several successful pilot and commercial scale demonstrations of post-combustion capture (PCC) systems with coal-fired power plant, mostly using amine-based solvent absorption processes. Other processes using solid sorbent adsorption, chilled ammonia and membrane separation are also in development, and some are being demonstrated at large pilot scale.

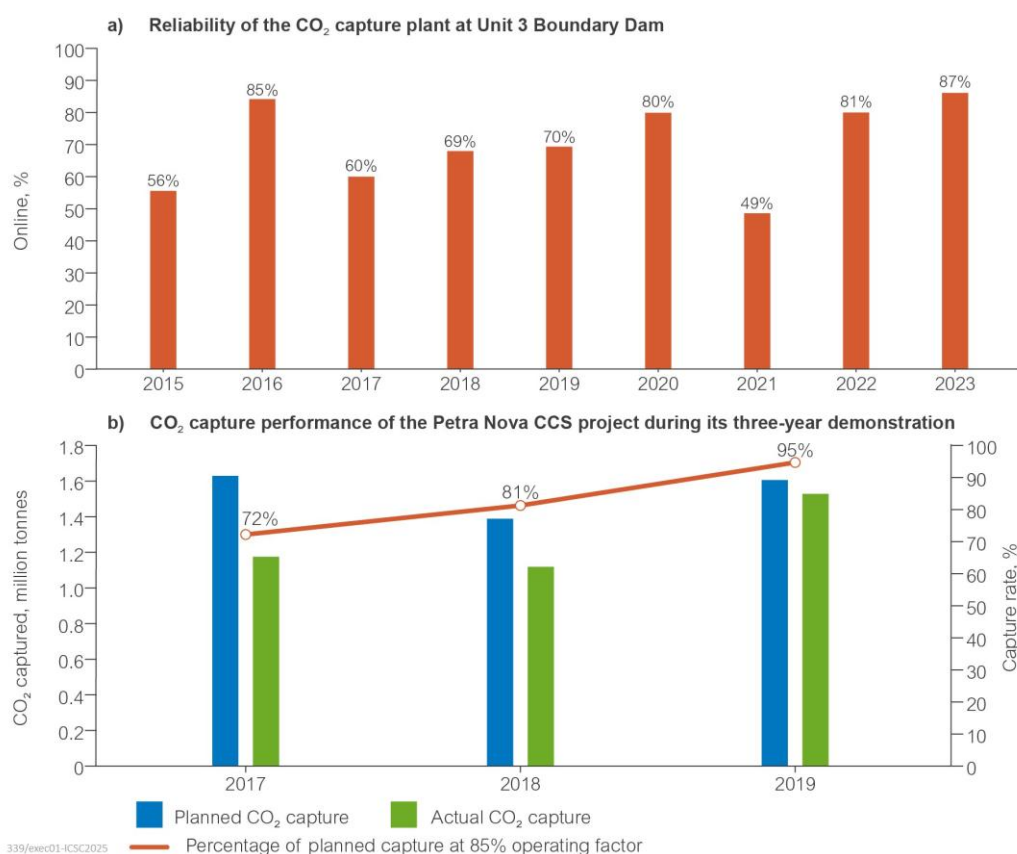


Figure 1 The performance of PCC at Boundary Dam and Petra Nova

Commercial-scale amine-based PCC systems have been demonstrated on existing coal power generating units such as Boundary Dam, Canada and Petra Nova, USA. Several large-scale amine solvent PCC demonstration facilities with up to 1.5 MtCO₂/y capacity are underway at coal-fired power plants in China. Figure 1 shows the improving performance of PCC at Boundary Dam and Petra Nova over time. Amine-based PCC has been proven to work on coal power plants at commercial scale and can achieve a CO₂ capture efficiency of above 95%. The technology continues to evolve, leading to optimised process and engineering designs, improved performance and reliability of the processes, and lowered capital and operating costs. Various amine-based PCC systems are commercially available. Any near-term application of CCUS on coal-fired power plants will most likely use amine-based PCC technology.

FLEXIBLE OPERATION OF COAL POWER PLANTS

The increasing share of variable renewable energy means that coal power plants are required to operate more flexibly to balance the grid. For existing conventional coal power plants, operating flexibility can be improved through retrofitting certain plant components, making operational modifications, and implementing advanced instrumentation and control (I&C) systems. The flexibility of the combustion system can be improved by changing the mill size, the number of mills in operation, optimising the fuel and combustion air ratio and distribution, and better burner design and arrangement. Further, measures such as reliable coal ignition and flame detection, installing a hot gas generator and/or indirect firing, and optimising auxiliary systems can lower minimum loads, increase ramp rate and allow faster start-up.

The water-steam cycle for power generation can be optimised by engineering retrofits to enable steam bypass of processes such as feedwater heater, condensate and economiser, installing thermal energy storage, and feedwater repowering; the results are leading to increased flexibility and higher efficiency. Using high-grade materials to enable a thinner design of thick-walled components, sliding pressure operation mode, and improved operation procedures will also enhance flexibility.

The I&C system is the link joining all the factors important for efficient plant operation and can be the most cost-effective way to improve plant performance. Fine-tuning the existing control system can often improve plant flexibility and efficiency. Enhanced digitalisation provides enabling technologies for improving flexibility, performance and efficiency as well as reduced costs. Further, changes to certain plant operational practices with proper operator training can unlock latent flexibility at existing plants.

FLEXIBILISING THE OPERATION OF CO₂ CAPTURE SYSTEMS

For integrated power plants and PCC, capture systems must follow the operational regime of the host plant and achieve high levels of CO₂ capture at the lowest cost. Hence, capture plants need to be sufficiently flexible to deal with the load variations of the host power plants. One measure to flexibilise PCC plant operation is segregated solvent inventory with solvent storage, where the lean and rich solvent can be circulated in two separate shorter loops when needed. The solvent storage tank provides enough lean solvent in the system prior to start-up and sufficient capacity to store rich solvent until normal regeneration operation is reached. With this arrangement, the absorber can start to capture CO₂ as soon as the boiler is fired up. The rich solvent built up during start-up is worked off after the regenerated solvent supply is established. Once regeneration of the amine solvent is established, the circulation is transitioned from segregated inventory to circulating inventory or, normal operation. Consequently, the start-up time of the PCC system is decreased while high CO₂ capture efficiency during the start-up is ensured.

Another measure is to install a solvent storage system, where the energy and capacity penalty due to the operation of PCC can be shifted in time by storing rich solvent and regenerating it later. When power demand rises, the rich solvent from the absorber is sent to a rich solvent storage tank instead of the desorber. CO₂ capture in the absorber operates as normal by drawing the lean solvent from a lean solvent

storage tank. Meanwhile, steam for solvent regeneration is diverted to the steam turbine to boost net power output. When power demand decreases, the absorber and desorber return to their normal operation mode and regenerate an extra amount of rich solvent to replenish the lean solvent tank which leads to a lower net power output.

During power plant start-up sequence, steam is produced at various pressures that cannot be admitted to the steam turbines. This steam is typically dumped into the main condenser. This waste ‘early steam’ can be used in the desorber/reboiler to accelerate the start-up sequence of the PCC process through equipment preheating and solvent regeneration. Similarly, substantial waste steam is available during the shutdown sequence which could be used for further solvent regeneration. This approach can reduce start-up time of PCC and increase the average capture rate of a given starting/shutdown sequence. Combining this technology with solvent storage can improve energy and CO₂ capture efficiency and hence, lower the cost.

Installing a thermal energy storage system can provide instant thermal energy to pre-heat the desorber and reboiler during start-up. Also, during peak demand, the stored thermal energy can be used for solvent regeneration and to send all the steam from the steam generator to the turbine to increase the net power to the grid. The heat storage can be topped up during low-load operation period and/or prior to power plant shutdown and continue regeneration operation in the desorber/reboiler to treat residual flue gas. Stable operation of PCC at lower load can be achieved by using multiple smaller-sized items such as absorbers, desorbers and CO₂ compressors. The flexibility of PCC systems can also be enhanced by using advanced I&C systems.

The flexible operation of PCC involves trade-offs between performance, efficiency and costs. The CO₂ removal efficiency of a PCC plant will be lower during flexible operation than during steady-state operation. However, adopting a flexible PCC system will improve the position of a coal power plant with CCS in the merit order for dispatch with some financial benefits. Therefore, the design of a PCC system for power plants needs to balance flexibility, cost, and minimising CO₂ emissions.

The role of coal power in the energy transition will not disappear but rather, with existing and innovative technologies, it can and will evolve into a more dynamic and responsive function. CO₂ capture technology on coal power plants works at commercial scale. Therefore, CCUS can be used to decarbonise coal power generation. PCC-equipped coal power plants can have certain operational flexibility. They can have an important role in modern power systems to provide low-emission flexibility, capacity and other vital system services to the grid.

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Each executive summary is based on a detailed study which is available separately from: www.sustainable-carbon.org. This is a summary of the report: Operational flexibility of coal power plants and carbon capture by Dr Qian Zhu, ICSC/339, ISBN 978-92-9029-662-1, 78 pp, May 2025.