

# Transformation and Development Path of China's Thermal Power Generation Industry under Dual Carbon Goal

Zepeng Li<sup>1, a, \*</sup>

<sup>1</sup>Department of Environmental Science and Engineering, North China Electric Power University, Baoding 071003, China

<sup>a</sup> lizepeng@ncepu.edu.cn

**Abstract:** In the next few decades, the transformation and development direction of China's power industry is achieving dual carbon goal, thermal power units with high installed capacity and large carbon emissions are the main targets of carbon emission reduction. This paper expounds the connotation of dual carbon goal in power industry, and then discusses the transformation and development path of China's thermal power generation industry under the dual carbon goal from 3 directions: carbon mitigation from the source, carbon mitigation from the sink and improvement of the grid's ability to absorb new energy power. The results show that carbon mitigation from the source can be achieved through co-firing biomass with coal for thermal power generation and energy saving of thermal power generating unit under all working conditions. Post-combustion carbon capture is the mainstream technology to improve the carbon dioxide absorption capacity of the sink. Optimizing the flexible operation control strategy of coal-fired power plants can improve the absorption capacity of the grid for new energy power. This paper can provide reference for researchers who want to understand the development trend of thermal power generation industry in China.

**Keywords:** CO<sub>2</sub>, Dual carbon goal, Thermal power generation industry, Development.

## 1. Introduction

In September 2020, China put forward "Dual Carbon Goal" at the United Nations General Assembly, which not only pointed out the way for China's green low-carbon transformation, but also injected new momentum into promoting global climate governance. Electric is the most widely used, the most convenient and the most environmentally friendly secondary energy, which plays an extremely important role in the development of national economy and the improvement of people's living standards. In China, thermal power generation is the pillar of the energy field, and its scale has long been the first in all power generation technologies. Traditional thermal power generation is heavily dependent on fossil fuels (especially coal), which produces a large amount of CO<sub>2</sub> in the process of power generation. Carbon emission reduction in power industry is necessary to achieve dual carbon goal, and the transformation of thermal power (especially coal-fired power generation) is the primary task of carbon emission reduction in power industry.

A lot of forecasts have been made on the development path of thermal power generation industry, but most of them only focus on a specific direction. This paper summarizes the previous research results and point out the transformation and development of China's thermal power generation industry under the dual carbon goal.

## 2. Dual Carbon Goal in Power Industry

### 2.1. Definition of Dual Carbon Goal

"Dual Carbon Goal" refers to "Carbon Emission Peak" and "Carbon Neutrality". The (Inter-governmental Panel on Climate Change, IPCC) defines the "Carbon Emission Peak" as the annual CO<sub>2</sub> emission of a region or an industry reaches its historical maximum, and then enters the process of continuous decline. "Carbon Emission Peak" is the historical turning point of CO<sub>2</sub> emissions from increase to decrease. "Carbon Neutrality" refers to the balance between the amount of CO<sub>2</sub> emitted into the atmosphere in human activities and the amount of CO<sub>2</sub> removed from the atmosphere by carbon capture and storage technology. That is, the net emission of CO<sub>2</sub> from human activities becomes zero.

### 2.2. Intension of Dual Carbon Goal in Power Industry

Reaching the peak of CO<sub>2</sub> emissions in a given year and then followed by a downward trend in the range of fluctuations is "Carbon Emission Peak in Power Industry". This is basically the same as the IPCC definition. However, the definition of "Carbon Neutrality in Power Industry" is quite different from that of IPCC. The author believes that "Carbon Neutrality in Power Industry" means to minimize CO<sub>2</sub> emissions on the premise of ensuring power supply, rather than zero emissions. As show in Table 1, all existing power generation technologies worldwide emit CO<sub>2</sub> during operation.

**Table 1.** Average CO<sub>2</sub> emission intensity of global power sources g/(kW·h) [1]

Power source	Coal power	Oil power	Gas power	Heat power	Biomass power
Emission intensity	1001	840	469	45	18

For thermal power (especially coal-fired power), even if carbon capture and storage projects are installed, net zero emissions of CO<sub>2</sub> cannot be achieved due to the low removal efficiency. It is impossible for power plant to achieve net zero emission of CO<sub>2</sub> alone, reducing carbon emissions in the process of power generation as much as possible is a more realistic way.

### 3. Carbon Mitigation from the Source

Reducing CO<sub>2</sub> emissions from the source is an effective way to achieve the dual carbon goal for power industry. The author believes that carbon emissions per unit of thermal power generation need to be continuously reduced, which can be realized by utilizing low carbon fuels and improving energy efficiency.

#### 3.1. Co-firing Biomass with Coal for Thermal Power Generation

Biomass itself is considered to be zero carbon emissions because CO<sub>2</sub> produced during biomass combustion is equivalent to the CO<sub>2</sub> absorbed by photosynthesis during growth [2]. Coal-firing biomass with coal is a method that use biomass to replace coal partially to produce electricity, 3 ways included are as follows: (1) Direct mixed combustion of biomass, which requires high performance of fuel treatment process and combustion equipment. (2) Biomass gasification coupling, which has good universality and little effect on raw coal combustion system. (3) Biomass pyrolysis mixed combustion power generation, which has a wide range of

applications, helping to achieve complementary high and low energy.

Coal-firing biomass with coal is of great significance in energy conservation, emission reduction and energy structure adjustment. Its main advantages are as follows: (1) Solid biomass partly or completely replaces coal as fuel, which can significantly reduce CO<sub>2</sub> production in the process of combustion power generation. (2) Biomass is cheap and easy to get, the cost of power generation is low. (3) Biomass fuel involved in co-firing has strong flexibility, and the power generation system has strong adaptability to the fluctuation of fuel supply.

#### 3.2. Energy Saving of Thermal Power Generating Unit under All Working Conditions

“Energy Saving of Thermal Power Generating Units in All Working Conditions” means to minimize the energy loss in all aspects of thermal power generation through technological innovation and process optimization, so as to improve energy efficiency and reduce CO<sub>2</sub> emissions per unit of power generation.

The analysis results of the heat method based on the first law of thermodynamics and the entropy method based on the second law of thermodynamics show that the heat loss of power station mainly exists in the cold end thermal system, and the loss of work capacity is concentrated in the boiler combustion system, as show in Table 2.

**Table 2.** Thermal loss ratios of each subsystem of a typical coal-fired power plant [3]

Heat loss system	Medium parameter power station	High parameter power station	Ultra-high parameter power station	Supercritical parameter power station
Boiler	11	10	9	8
Pipeline	1	1	0.5	0.5
Cold end	61.5	57.5	52.5	50.5
Steam turbine	1	0.5	0.5	0.5
Generator	1	0.5	0.5	0.5

##### 3.2.1. Optimization of Cold End Thermal System

The cold end heat release system composed of condenser and cooling tower discharges working fluid from 50 % of boiler heat absorption to the environment, and its operation performance is a key factor restricting the improvement of thermal cycle efficiency. The author believes that the performance of the cold end thermal system can be improved by optimizing the operation of cooling tower and the arrangement of the condenser tube bundle.

Considering the operation cost and environmental benefits, the heat carried by the cooling circulating water of the condenser is generally discharged into the environment through the natural ventilation cooling system [4]. The

adaptability to different meteorological conditions is the main indicator to measure the operation performance of natural ventilation dry cooling system. By optimizing the distribution of circulating water flow, the system can adapt to the change of environmental wind. By changing the inlet temperature of circulating water into the tower, the system can adapt to the change of environmental temperature.

The typical design structure of the condenser is shown in Figure 1. The exhaust steam of the low-pressure cylinder and the turbine enters the condenser tube bundle area from top to bottom and heats with the circulating cooling water in the tube. After condensation, it is sent to the boiler feed water system.

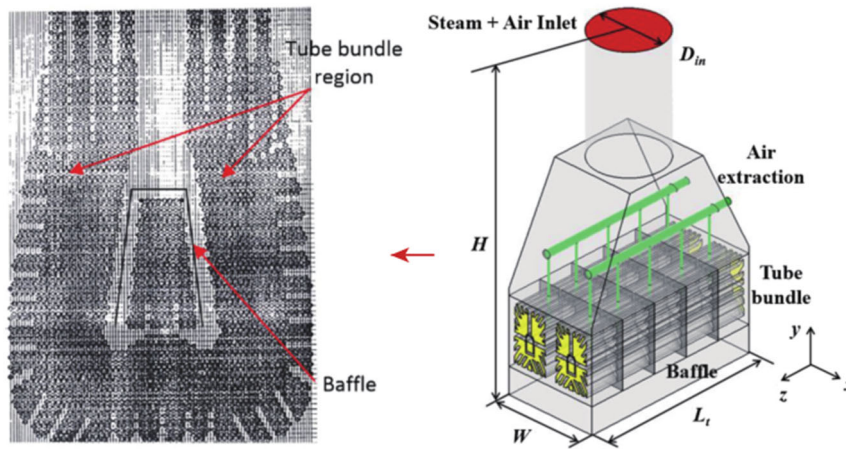


Figure 1. Configuration of the industrial condenser [5]

When arranging the heat pipe bundle inside the condenser, the upstream area of the front tube bundle need to be increased, and the internal eddy current should be avoided as far as possible.

### 3.2.2. Optimization of Boiler Combustion System

The energy conversion process in boiler is mainly the transformation from chemical energy released by fuel combustion to heat energy released by working medium. Optimization of boiler combustion system need to be based

on the second law of thermodynamics to reduce the loss of combustion process and energy transport process with different grades [6].

The heat loss of the boiler is mainly caused by the heat loss of the exhaust flue. The thermal efficiency of the boiler can be improved by optimizing the flow transfer process of the exhaust flue heat recovery. The tail flue structure of the boiler is shown in Figure 2.

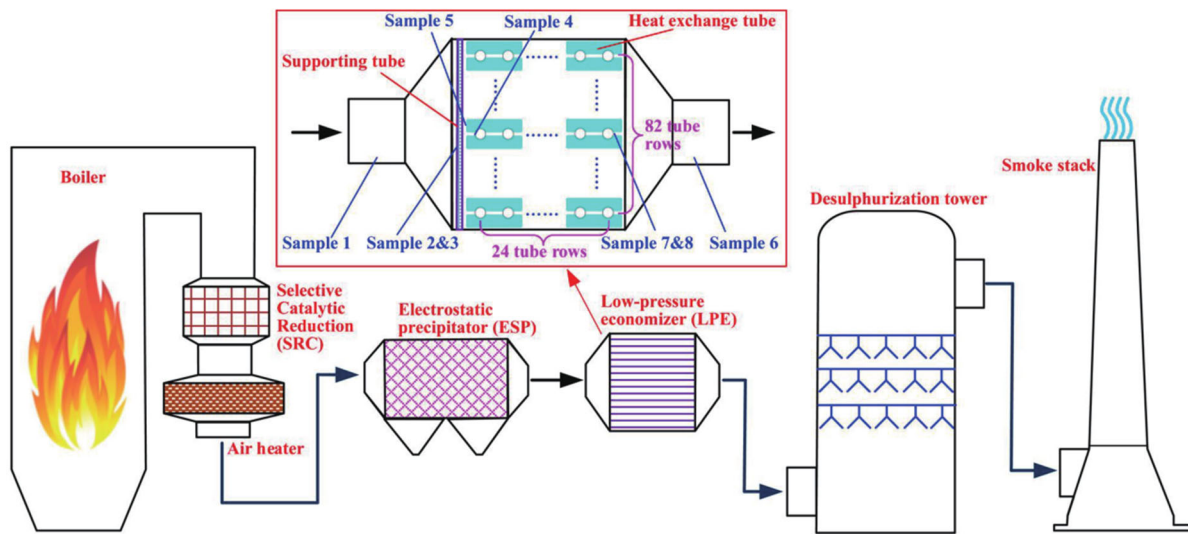


Figure 2. Schematic diagram of the low pressure economizer [7]

Enhancing the heat transfer process is the main way to optimize heat recovery of tail flue. Air heater and low pressure economizer are the main equipment for recovering smoke exhaust heat. Setting the parameters of air heater according to the flue gas heating temperature range and arranging the low pressure economizer in a reasonable position can reduce the heat loss of boiler exhaust gas and reduce the amount of high-grade fuel steam, thereby improving the thermal efficiency and power cycle efficiency of power plants. In addition, it is crucial to maintain the heat transfer capacity of the air preheater as much as possible under the premise of satisfying the heat transfer.

## 4. Carbon Mitigation from the Sink

Increasing CO<sub>2</sub> consumption from the sink is also an effective way to achieve the dual carbon goal of the power

industry, which is mainly realized by “CCS”. “CCS” is the abbreviation of “Carbon dioxide Capture and Storage”, which includes capture and storage of CO<sub>2</sub> generated during the combustion of fossil fuels. Limited by space, the author only discusses some mainstream carbon capture technology. According to the order of carbon capture and combustion process, carbon capture technologies can be divided into 3 types: pre-combustion capture, in-combustion capture and post-combustion capture. Among them, post-combustion capture is widely used because its device is located downstream of the pollutant removal system and does not change the power plant structure and energy utilization mode. At present, the applied post-combustion capture technologies include physical adsorption, chemical absorption and membrane separation. Among them, chemical absorption is widely used in large-scale carbon capture projects worldwide.

## 4.1. Physical Adsorption

Physical adsorption means to adsorb the CO<sub>2</sub> from industrial flue gas selectively by using specific adsorbents. Then, release the adsorbed CO<sub>2</sub> by reducing pressure or increasing temperature to achieve desorption and regeneration of the adsorbent. Physical adsorption technology mainly includes pressure swing adsorption (PSA) and temperature swing adsorption (TSA), the former is more commonly used.

PSA is a method that use the solid adsorbents filled in the adsorption tower to adsorb CO<sub>2</sub> under high pressure, and then operate the vacuum pump to reduce the pressure of the adsorption tower so that the CO<sub>2</sub> can be desorbed, and finally high concentration of CO<sub>2</sub> is obtained.

## 4.2. Chemical Absorption

Chemical absorption is the most widely used technology in the post-combustion capture process, which means to separate the required components selectively from the gas phase efficiently and rapidly by using chemical reactions. The essence is that the alkaline absorbent solution contacts with CO<sub>2</sub> and reacts to form unstable salts. After changing the reaction conditions, those salts will decompose and release CO<sub>2</sub>. Development of efficient and environmentally friendly chemical absorbents, improvement of reaction equipment and optimization of integrated process are 3 major research directions of chemical absorption.

Organic amine solution is a common absorbent for chemical absorption, which is concentrated in the carbon capture of actual industrial flue gas. Monoethanolamine (MEA) is a widely used organic amine absorbent. It belongs to primary amine with strong alkalinity and can react with CO<sub>2</sub> completely and rapidly. However, MEA has many disadvantages: (1) Its aqueous solution is easy to foam and degrade. (2) The product formed by the reaction with CO<sub>2</sub> is stable, resulting in high solution regeneration temperature and large steam consumption. (3) The corrosion is strong and the damage to the device is large. In contrast, there is no active hydrogen atom in the molecule of MDEA, which means that MDEA is not easy to be degraded and deteriorated. Coupled with its low regeneration energy consumption, MDEA is gradually applied worldwide.

## 4.3. Membrane Separation

Based on the principle that the membrane composed of polymers has different relative permeability to different gas molecules, the membrane separation can capture CO<sub>2</sub>. When the flue gas passes through the membrane module, the CO<sub>2</sub> in it will be preferentially selectively absorbed by the membrane due to its relatively fast permeation rate, and then spread to the low pressure side. On the contrary, gases with relatively slow penetration rates will remain at the high pressure side. Finally, different gas components are separated on different sides of the membrane module to capture and enrich CO<sub>2</sub>.

Membrane separation has small equipment investment, simple process and low energy consumption. However, it cannot run in extreme working conditions. Besides, its working load is not enough and the concentration of CO<sub>2</sub> is low. Further study is needed to remove the application limitation of it.

## 5. Improvement of the Grid's Ability to Absorb New Energy Power

To achieve the goal of carbon neutrality, China must develop renewable energy. Over time, the share of thermal power will gradually decrease. Different from traditional power generation, new energy electric generation has poor controllability and cannot be used as a power guarantee, so thermal power cannot be completely replaced. In addition, new energy power has strong random volatility. Its large-scale integration into the power grid will greatly reduce the controllability of the power supply side in the power system. The author believes that with the increasing proportion of new energy power in the power grid, the flexible operation ability of coal-fired units need to be improved to ensure the safe and efficient operation of the power system. The flexible operation control of coal-fired units means to the rapid and deep variable load control of units through advanced control technology, which requires the minimum load operation of units and flexible output power.

Coordinated control system (CCS) is the core of automatic generation control (AGC) for coal-fired generating units. In essence, it uses the heat storage at the boiler side of the unit to change the flow rate of working steam through rapid action of the main control valve, so as to achieve the purpose of response to the change of unit load prompt. A large amount of heat is stored in the coal-fired unit. Changing the flow rate of working fluid and reducing enthalpy can release the heat storage of the system, and then change the load. Limited by space, the author focuses on 3 key technologies. They are steam extraction regulation of heating unit, plant-level load optimal distribution and condensate throttling.

### 5.1. Steam Extraction Regulation of Heating Unit

The extraction steam that was originally used for heating is fed into the steam turbine to increase the power supply load, which is the extraction steam regulation of the heating unit. It can not only improve the load change rate of the unit, but also shorten the dead time of the unit to cross the load response. The author believes that by redesigning the operation strategy of the heating unit, the heating unit can change part of the heating load into the power generation load in a short time when there is peak shaving demand on the grid side so that the flexible operation of the unit load can be realized.

### 5.2. Plant-level Load Optimal Distribution

The optimal distribution of plant-level load can reduce the number of controlled units on the grid side, thereby improving the calculation speed and improving the flexibility of power supply side operation control. Compared with the direct dispatching of a single unit, the optimal load distribution at the plant level can even double the variable load capacity.

Taking the rapidity as the index of optimal load distribution at plant level, the rapidity and economy of the unit operation are weighed by adjusting the weight of the objective function, which ensures that the power plant can meet the essential requirement of rapid response to load demand and minimizes coal consumption [8].

### 5.3. Condensate Throttling

The basic principle of condensate throttling is that by quickly shutting down the condensate of the unit and pumping

steam from low pressure heaters at all levels, instantaneously increasing the amount of steam entering the low pressure cylinder for work, thereby rapidly increasing the unit load, as show in Fig. 3. By means of valve throttling regulation or self-

balancing of the heater, the steam originally used to heat the feed water works in the steam turbine, thereby changing the unit load.

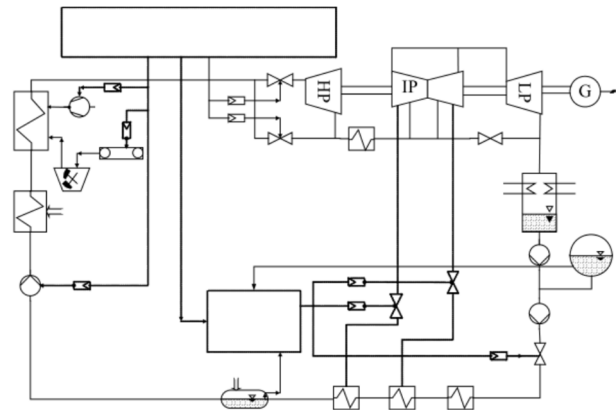


Figure 3. Schematic diagram for the condensate throttling [9]

## 6. Conclusions

It is very important for achieving dual carbon goal to transform China's thermal power generation industry. The author concludes the concept of "Dual Carbon Goal" and makes further explanations based on the characteristics of the power industry. This paper discusses 3 major development directions of carbon emission reduction in thermal power generation plants: carbon mitigation from the source, carbon mitigation from the sink and improvement of the grid's ability to absorb new energy power. Carbon mitigation from the source mainly includes 2 directions: co-firing biomass with coal for thermal power generation and energy saving of thermal power generating unit under all working conditions. The latter can be realized by optimizing the cold end thermal system and boiler combustion system. Post-combustion carbon capture is the mainstream technology to enhance CO<sub>2</sub> absorption capacity of sinks, which mainly includes physical adsorption, chemical absorption and membrane separation. Among them, chemical absorption is the most widely used method, and the development of new industrial absorbents is a hotspot. Utilizing low carbon power and gradually eliminating high carbon power are the development trend of electric power industry under the dual carbon goal. Optimizing the flexible operation control strategy of coal-fired power plants can improve the ability of power grid to absorb new energy power, which helps to promote the safe and efficient large-scale integration of new energy power. It can be realized by steam extraction regulation of heating unit, plant-level load optimal distribution and condensate throttling. This paper summarizes the transformation and development directions of thermal power generation industry under dual carbon goal, which is helpful for researchers to understand the frontier hot issues.

## References

- [1] IPCC, 2018: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 616 pp.
- [2] IEA, Biomass with carbon capture and storage (BECCS/Bio-CCS)[R]. Paris: IEA Greenhouse Gas R&D Programme, 2017: 1-72.
- [3] T. Ye, Y. Zhang, Thermal Power Station (in Chinese). Beijing: China Electric Power Press, 2017.
- [4] G. Davis, S. Selkowitz, M. Brook, Comparison of alternate cooling technologies for California power plants: Economic, environmental and other tradeoffs. Public Interest Energy Research. California Energy Commission, 2003.
- [5] Y. Park, S. Yoon, Y. Seo, et al, A study on the optimal arrangement of tube bundle for the performance enhancement of a steam turbine surface condenser. Appl Thermal Eng, 2020, 166: 114681.
- [6] C. He, J. Liu, Y. Gu, Research on evaluation method of coal-fired power plant boiler system efficiency (in Chinese). J China Coal Soc, 2015, 40:951-958.
- [7] C. Wang, B. H. L. Yan, et al, Thermodynamic analysis of a low-pressure economizer based waste heat recovery system for a coal-fired powerplant. Energy, 2014, 65: 80-90.
- [8] Z. Wang, J. Liu, W. Tan, et al, Multi-objective optimal load distribution based on speediness and economy in power plants [J]. Proceedings of the CSEE, 2006, 26(19): 86-92(in Chinese).
- [9] G.K. Lausterer, Improved maneuverability of power plants for better grid stability[J]. Control Engineering Practice, 1998, 6(12): 1549-1557.