Asia-Pacific
Economic Cooperation

'Best' Coal-Fired Power Plant and Cogeneration Case Studies

Better performance improves readiness for carbon management

APEC Energy Working Group
Expert Group on Clean Fossil Energy
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List of Acronyms

a.r.	As received
AEP	American Electric Power
APEC	Asia Pacific Economic Cooperation
APERC	Asia Pacific Energy Research Centre
AQCS	Air quality control system
B&W	Babcock & Wilcox
BIM	Building information modeling
BMCR	Boiler maximum continuous rating
BTMU	Bank of Tokyo-Mitsubishi
Btu	British thermal unit
CB&I	Chicago Bridge and Iron
CCUS	Carbon capture, utilization, and storage
CFB	Circulating fluidized bed
CO_2	Carbon dioxide
DCS	Digital control system
DRH	Double reheat
EGAT	Electricity Generating Authority of Thailand
EPC	Engineering, procurement, and construction
ESP	Electrostatic precipitator
EVNGENCO3	Vietnam Electricity Power Generation Corporation 3
FGD	Flue gas desulfurization
ft	Foot
ft^3	Cubic foot
g	Gram
GE	General Electric
GJ	Gigajoule
gpm	Gallons per minute
GWh	Gigawatt-hour
h, hr	Hour
HARP	Heater above the reheat pressure
HELE	High-efficiency, low-emission
Hg	Mercury
HHV	Higher heating value
HP	High pressure
IGCC	Integrated gasification combined cycle
IGFC	Integrated gasification fuel cell
INTREX	Integrated recycle heat exchanger
IP	Intermediate pressure
JBIC	Japan Bank for International Cooperation
KEPCO	Korea Electric Power Corporation
kg	Kilogram
kJ	Kilojoule
km	Kilometer
KOSPO	Korea Southern Power
KOWEPO	Korea Western Power Co. Ltd.
kPa	Kilopascal
kV	Kilovolt
kVA	Kilovolt-ampere
kW, kWe	Kilowatt electric
kWh	Kilowatt-hour
L&T	Larsen & Toubro
lb	Pound
LHV	Lower heating value
LP	Low pressure
m	Meter
m^3/min	Cubic meters per minute
MATS	Mercury and Air Toxic Standards
mg/m^3	Milligrams per cubic meter
mg/Nm^3	Milligrams per normal cubic meter
MHPS	Mitsubishi Hitachi Power Systems
MPa	Megapascal
Mt	Metric ton
MW, MWe	Megawatt electric
MWh	Megawatt-hour
NO_x	Nitrogen oxides
OFA	Overfire air
PC	Pulverized coal
PJFF	Pulse jet fabric filer
PM	Particulate matter
ppm	Parts per million
PRC	People's Republic of China
psi	Pound per square inch

psia	Pound per square inch absolute
psig	Pound per square inch gauge
ReACT™	Regenerative Activated Coke Technology
s	Second
S&L	Sargent & Lundy
SC	Supercritical
SCR	Selective catalytic reduction
SDA	Spray dryer absorber
SHI	Sumitomo Heavy Industries, Ltd.
SNCR	Selective non-catalytic reduction
SO_2	Sulfur dioxide
SO_X	Sulfur oxides
SPE	Solid particle erosion
STG	Steam turbine generator
T-G	Turbine-generator
TPY	Tons per year
U.S.	United States
US$	United States dollars
USC	Ultra-supercritical
VCHEC	Virginia City Hybrid Energy Center
VWO	Valve wide open
WFGD	Wet flue gas desulfurization
yr	Year
°C	Degrees Celsius
°F	Degrees Fahrenheit

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Acknowledgments

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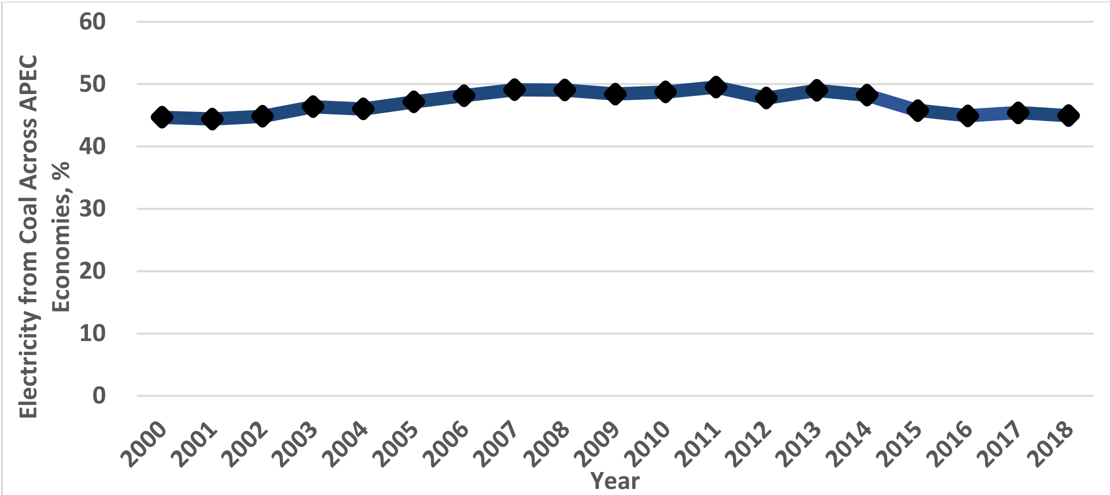
Introduction

While a global energy transition is underway, coal-fired power generation still holds a significant share of the electricity supply for many economies in the Asia Pacific Economic Cooperation (APEC) region (Table 1 for individual APEC economies and Figure 1 for cumulative economies) and for many other economies around the world, and some economies are building or planning to build additional coal capacity. Several APEC economies have already started or have recently committed to reducing coal's share of their generation mix and/or phasing out coal-fired power generation in line with the ongoing global transition to low emissions of carbon dioxide (CO_2). To support these policy decisions, some governments and financial institutions in some APEC economies and other economies around the world have restricted or eliminated financing of coal power generation.

Table 1 – Coal's Share of Electricity Generation in APEC Economies

Economy	Electricity from Coal		
	2000	2010	2018
Australia	83.0%	71.3%	60.5%
Brunei Darussalam	0.0%	0.0%	0.0%
Canada	19.4%	13.2%	7.7%
Chile	21.1%	27.9%	36.3%
People's Republic of China	74.7%	76.7%	67.1%
Hong Kong, China	46.0%	46.0%	45.0%
Indonesia	37.3%	40.3%	56.4%
Japan	21.1%	26.7%	32.3%
Malaysia	6.3%	41.6%	45.3%
Mexico	9.2%	11.7%	8.7%
New Zealand	3.9%	4.6%	3.6%
Papua New Guinea	0.0%	0.0%	0.0%
Peru	1.7%	2.4%	0.2%
The Philippines	36.8%	34.4%	52.1%
Russia	20.0%	16.0%	16.0%
Singapore	0.0%	0.0%	1.3%
Republic of Korea	38.6%	44.1%	44.1%
Chinese Taipei	47.1%	49.5%	47.6%
Thailand	18.6%	17.7%	19.1%
United States	52.9%	45.8%	28.7%
Viet Nam	11.8%	25.2%	42.2%

*All values are from the Expert Group on Energy Data Analysis (1)



*All values are from the Expert Group on Energy Data Analysis (1)

Figure 1 – Coal Contribution to Electricity Generation Across All APEC Economies

In addition, as shown in Figure 2 from the Asia Pacific Energy Research Centre's (APERC's) Coal Report 2021 (1), APEC economies are pursuing a range of decarbonization measures, including switching and/or cofiring lower carbon fuels in existing coal units. These fuels include gases (natural gas, ammonia, and hydrogen) and solids (biomass and wastes) that lower CO_2 emissions by reducing coal's share of the thermal input into boilers designed for coal firing. In addition, a few APEC economies (Canada, People's Republic of China [PRC], and the United States [U.S.]) have retrofitted existing coal-fired power plants with carbon capture, utilization, and storage (CCUS) to demonstrate low carbon development (i.e., capturing >90% of the treated gas flow) although the economics of this strategy are usually difficult, especially for older coal units, without government support. Beyond these demonstration facilities, APEC economies have CCUS facilities in the development pipeline that would capture about 25 million metric tons (Mt) of CO_2 per year (yr), as shown in Figure 3. (1)

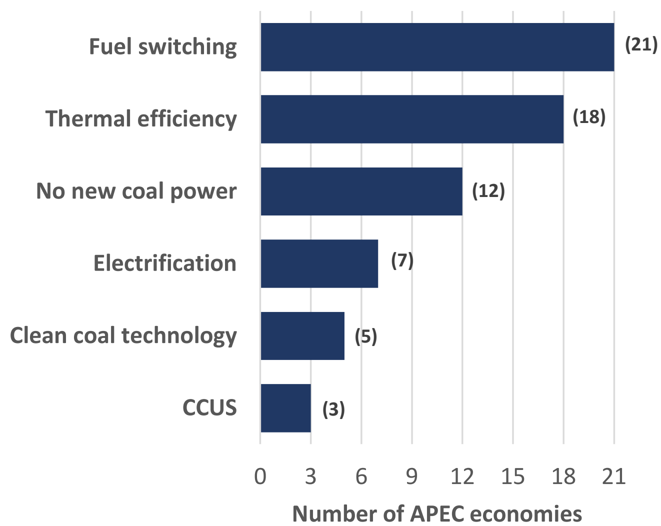


Figure 2 – Current Measures to Promote Decarbonization in Coal-Consuming Sectors[1]

[1] Used with permission from APERC (27)

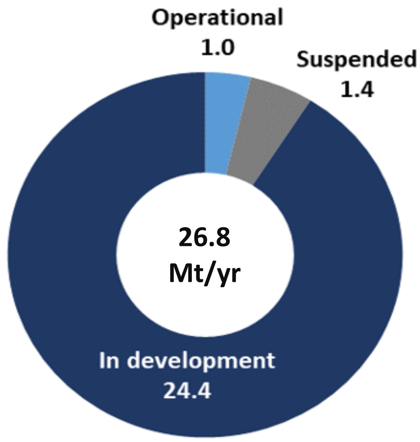


Figure 3 – Coal power-related CCUS capacities in the APEC region[2]

A key element of the global energy transition is retiring low-efficiency, highly polluting coal plants as quickly as possible. Around the world, most retiring coal units are not replaced by new, more efficient, and cleaner coal technology but by alternative lower-carbon energy sources, including natural gas and renewables, especially wind and solar. (2)

However, another reality is that a few economies in the region and around the world are still planning new coal generating capacity and many economies will continue operating their existing coal plants for many years, especially in the APEC region where many plants are newer and have not been fully amortized. This situation exists for a variety of reasons, including domestic and local politics and limited energy resource endowments (especially using natural gas as a transition fuel), along with energy and/or environmental policies, which includes perceived positive benefits of employment and high wages in their coal and power sectors and the reliability and security of coal-based power generation.

For these economies, if they do build new coal power plants, it is critical that they only deploy the 'best' (i.e., state-of-the-art) technologies and operating practices that will minimize fuel consumption and pollutant discharges. New coal power plants based on the highest efficiency technology possible, which also follow best-operating practices, will be best able to support the economics of CCUS as part of an overall strategy to reduce CO_2 emissions. Low-efficiency subcritical coal plants should not be built, unless absolutely required by equipment limitations dictated by unit generating capacity or other design or operating parameters. Also, retrofitting CCUS onto existing plants also will require adopting global best operating practices for efficiency and operations and maintenance, which have been adopted by coal plants in many of the case studies in this report.

This report does not attempt to identify the single 'best' coal power plant in the APEC region or globally—an impossible task given the myriad of plant designs and operating attributes, including coal quality, that had to be considered in developing the specifications for each plant to meet local market requirements. However, each of the plants described in the 16 case studies presented in this report highlights advancements in one or more technology design or operating features to improve the plant's performance. Such improvements include higher operating efficiency, reduced emissions of conventional pollutants, reduced water usage, and reductions in construction and/or operations costs. It is more feasible to add CCUS to higher efficiency coal plants owing in large part to the power required to

[2] Ibid.

operate the capture facility and to compress the CO_2 if it is to be injected into geologic formations for permanent storage.

After an extensive review of publicly available information on plants in the APEC region, 16 plants with sufficient publicly available information for informative case studies were selected. Most of the information in these case studies was drawn from public sources with some information for a few plants obtained from personal contacts. Consequently, the breadth and depth of the information provided in the case studies varies.

Power Plant Case Studies

Anqing Power Plant Phase II

Distinguishing Features

Anqing Power Plant Phase II ("Anqing") is a nameplate rated at 2,000-MW coal-fired ultra-supercritical (USC) station in Anqing, Anhui Province in PRC. Shenwan constructed a high-capacity, efficient, low-emissions coal-fired power plant, which is currently considered to be the state of the art in the PRC. For example, the plant boasts the highest reheat steam parameters in PRC at the time operation began, resulting in the efficient utilization of coal with extremely low emissions. Many other technological approaches were also taken to improve the efficiency. For example, grade-9 regenerative extraction (i.e., extracting steam from 9 different locations in the steam turbine to optimize boiler feedwater heating) was adopted. As compared to the typical grade-8 regenerative extraction, heat consumption was reduced by 10 kJ/kWh (9.5 Btu/kWh) and standard coal consumption for power generation was reduced by 0.34 g/kWh. The scope of the construction of Anqing included two identical coal-fired USC power units, including limestone-gypsum wet flue gas desulfurization (WFGD) and selective catalytic reduction (SCR) facilities that were built simultaneously.

Technical Summary

The plant is owned by China National Energy Investment Group, the largest power company in the world by installed capacity, as well as the world's largest coal producer. The PRC is working to reduce the environmental footprint of coal utilization, including reducing the emissions of particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and CO_2 from coal power generation A major focus is to increase the use of high-efficiency, low-emission (HELE) coal technologies to meet the dual objectives of providing power and reducing the environmental impact of coal power generation.

Construction commenced on March 1, 2013, and the two units were commissioned with the compulsory 168 hours of full-load testing on May 31, 2015, and June 19, 2015. Therefore, the plant's effective construction period was remarkably short at just over 22 months. The projected investment was reportedly US$0.95 billion. Construction and commissioning of the Anqing units have fundamentally alleviated the power shortage in the Anqing region and increased the stability of the local grid. This has supported increased growth in industrial and agricultural production and an expanding service sector in the region and the larger province.

The plant's equipment and service providers are given in Table 2 and Table 3; its operating parameters are given in Table 4.

Table 2 – Anqing Equipment and Service Providers

Contribution	Contributor
Parent Company	National Energy Investment Group, Wenergy Group
Sponsor	Shenwan Energy Co, Ltd
USC Coal-Fired Units	Dongfang Boiler Group (boiler), Shanghai Turbine company (turbine) and Shanghai Electrical Machinery (generator)

Table 3 – Anqing Boiler Details

Supplier	Dongfang Boiler Group
Type	USC
Special Features	Domestic π type, opposed firing

Table 4 – Anqing Operating Parameters

Plant Name	Anqing Phase II Power Plant
Location	Anqing, Anhui Province, PRC
Online Date	Unit 1: May 2015 & Unit 2: June 2015
Nameplate Capacity	Unit 1: 1000 MW & Unit 2: 1000 MW
Coal Type	Bituminous Coal
Elevation	86.4 m (283.5 ft)
Dry Bulb Temperature	16.5 °C (61.7 °F)
Relative Humidity	76%

Steam conditions are provided in Table 5; the turbine and generator perform at >45 percent efficiency—no other details are publicly available.

Table 5 – Anqing Steam Conditions

Steam Conditions (VWO)	
Main Steam Flow Rate	808 kg/s (1,782 lb/s)
Main Steam Temperature	600 °C (1112 °F)
Main Steam Pressure	28 MPa (4061 psi)
Reheat Steam Flow Rate	0.816
Reheat Steam Temperature	620 °C (1148 °F)
Reheat Steam Pressure	5.6 MPa (812 psi)
Feedwater Temperature	304°C (579 °F)
Turbine Backpressure	4.89 kPa (0.7 psi)

There were numerous energy-saving projects that have been implemented in the plant, which reduced coal consumption, including the following:

- The high-efficiency USC steam turbines reduces the amount of coal needed per unit of power produced compared to plants that operate at SC or subcritical steam conditions.
- Reducing the backpressure on the steam turbines.
- Nine-stage regenerative steam extraction was adopted. Compared to the typical 8-stage regenerative extraction, this decreases heat consumption by 10 kJ/kWh (9.5 Btu/kWh) and standard coal consumption by 0.34 g/kWh.
- For the first time in the PRC, a high-yield wet cooling tower design (Figure 4) was used for a 1000-MW unit. Compared to a conventional cooling tower, the circulating pump lift is reduced by 10–11.5 m and noise decreased by 8–10 decibels. With this design, about 3,790 kW/h of parasitic energy is saved, leading to a decrease in the plant power consumption by 0.38 percent, and the standard coal consumption for power generation by about 1 g/kWh.

- Another approach to improve plant efficiency is maximizing the recovery of the waste heat in the flue gas and using it to preheat the boiler feedwater. Operating at the designed full load, the flue gas heat exchanger recovers 44,000 kW of heat, which reduced heat consumption by 45 kJ/kWh (42.6 Btu/kWh) and plant coal consumption by 1.65 g/kWh.

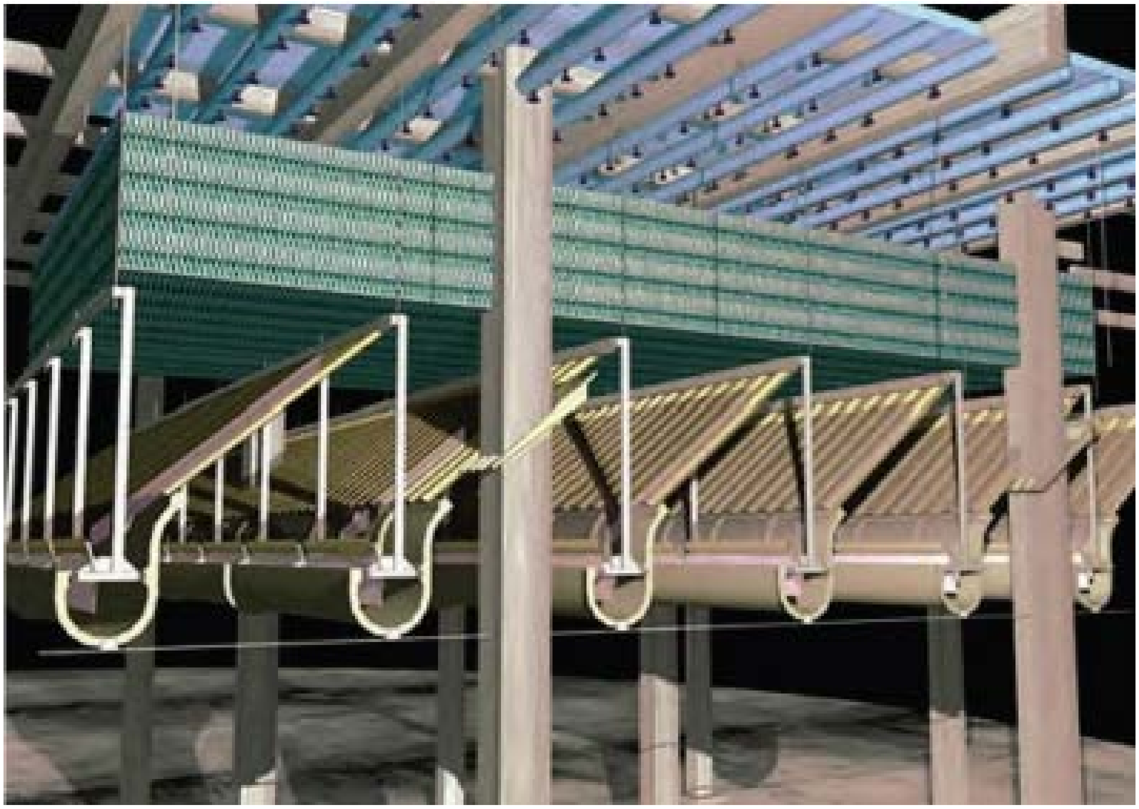


Figure 4 – Anqing High-Yield Wet Cooling Tower Internal Structure[3]

Emissions Profile

Anqing incorporated highly advanced flue gas treatment technologies based on an ultra-low emissions technology setup. The set up includes an electrostatic precipitator (ESP) with a low-temperature economizer, spin exchange coupling flue gas desulfurization (FGD) (Figure 5 and Figure 6), and a rotary tube bundle PM demister. Several of these flue gas treatment devices offer co-benefits that further reduce already low emissions. There are three separate processes in the power plant that remove PM from the flue gas:

1. The low-temperature economizer and high-frequency ESP with three chambers and five electric fields constitute the first segment of PM emissions control. The PM removal efficiency of the ESP is between 99.86 percent and 99.9 percent. The PM concentration in the flue gas exiting the ESP is approximately 25 mg/m^3 (1.6x10^{-6} lb/ft^3).

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[3] Used with permission from the IEA Clean Coal Centre, now the International Centre for Sustainable Carbon, an IEA Technology Collaboration Programme (13)

2. The secondary PM removal segment is the efficient spin-exchange coupling FGD that removes 60 percent of the remaining PM.
3. The third approach to PM removal is the low-temperature economizer and rotary tube bundle PM demister, which has a PM removal efficiency of more than 70 percent (PM emissions ≤ 3 mg/m^3).

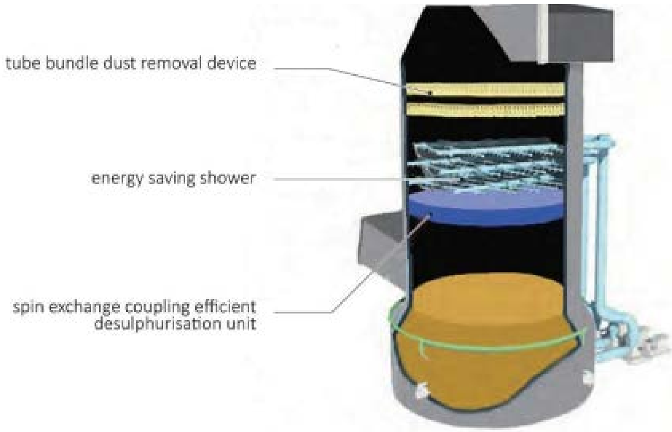

Figure 5 – Anqing FGD System, Based on Spin Exchange Coupling and Energy-Saving Spray[4]

Figure 6 – Anqing Spin Exchange Coupling Desulfurization and De-Dust Unit[5]

Compared to other PM capture options, the advanced-tube bundle PM removal technology takes up less space and fits well into the general layout of the project; in addition, the investment and operating costs are lower. In the spin-exchange coupling efficient FGD technology, a device termed a "turbulator" has been installed between the entering flue gas and first level of the FGD tower. This changes the flow state of the incoming gas from laminar to turbulent and reduces the gas-film resistance to increase the liquid-gas contact area and the gas-liquid mass transfer rate, which increases the SO_2 and PM removal efficiency. Low-NO_X combustion and SCR using urea as a reducing agent results in 95 percent NO_X reduction. This low-emissions technology drastically reduces emissions of PM, SO_2, NO_X, and heavy metals. The plant environmental performance is summarized in Table 6.

Table 6 – Anqing Emissions/Water Consumption Performance

Metric	Technology	Removal Efficiency (%)	PM Concentration
PM – Stage 1	ESP	99.89–99.9	25 mg/m^3 ($1.6x10^{-6}$ lb/ft^3)
PM – Stage 1	Spin exchange coupling FGD	60	-
PM – Stage 1	Rotary tube bundle PM demister	> 70	< 3 mg/m^3 (< $1.9x10^{-7}$ lb/ft^3)
SO_X	FGD	97.8–99.7	5 mg/m^3 ($3.1x10^{-7}$ lb/ft^3)
NO_X	Low NO_X Combustion	> 95	20 mg/m^3 ($1.2x10^{-6}$ lb/ft^3)

[4] Ibid.
[5] Ibid.

Caofeidian CR Power Plant

Distinguishing Features

Caofeidian CR (China Resources) Power Plant ("Caofeidian") is in the Caofeidian Industrial Zone, Tangshan City, Hebei Province, PRC. Its Phase II project comprises two 1,000-MW single- reheat USC units, with steam conditions of 28 MPa/600°C/620°C (4061 psia/1112°F /1148°F), making it the first project to include 1000-MW supercritical (SC) coal-fired generation units in Hebei Province. Caofeidian is a key practical project for in-depth strategic cooperation between China Resources Power Holdings Co., Ltd. (CR Power) and Hebei Province; early planning established the goal of building the world's most advanced thermal power units. Based on in-depth technical cooperation with Shanghai Shenergy Power Technology Co., Ltd., a series of unique and internationally-advanced, high-efficient, and clean technologies are used to achieve many breakthroughs in key technical innovations, refreshing the power industrial records in the world, and attracting high attention from the industry. Unit #3 of Caofeidian Phase II completed its 168-hour trial operation and was put into operation on May 24, 2019. Unit #4 completed its 168-hour trial operation (internal control) on August 3, 2019. (3)

Technical Summary

At the beginning of unit design, Shanghai Shenergy Power Technology Co., Ltd. comprehensively optimized the whole thermal system (Table 7). It was the first to adopt such advanced technologies (such as five-cylinder, six-exhaust-steam, ultra-low back-pressure turbine units) in the PRC. Additionally, other technologies were successfully applied, such as deep coupling of the unit thermal system, centralized and generalized variable frequency energy saving system, low-load high-efficiency operation, and boiler quick startup. The design coal consumption is less than 263 g/kWh (0.58 lb/MWh), i.e., the net lower heating value (LHV) efficiency is higher than 46.7 percent. Steam conditions are provided in Table 8. (3)

Table 7 – Caofeidian Equipment and Service Providers

Contribution	Contributor
Consulting	Shanghai Shenergy Power Technology Co., Ltd
Operator	China Resources
Boiler	B&W Beijing boiler
Steam Turbine	Shanghai Electric under license from Siemens
Generator	Shanghai Electric under license from Siemens

Table 8 – Caofeidian Phase II Steam Conditions

Steam Conditions (BMCR)	
Maximum Continuous Evaporation	845 kg/s (1,863 lb/s)
Main Steam Temperature	605°C (1,121°F)
Main Steam Pressure	29.3 MPa (4,250 psia)
Reheat Steam Flow Rate	817 kg/s (1,801 lb/s)
Reheat Steam Temperature	623°C (1,153°F)
Reheat Steam Pressure	6.2MPa (899 psia)
Feedwater Temperature	303°C (577°F)

The coordinated use of technologies such as integrated desulfurization and dedusting as well as primary and secondary measures deNOx is realized to better guarantee "ultra-low emissions" of the project. Caofeidian set a new international benchmark for the coal-fired power generation industry and provides an excellent example for other new coal-fired power units. An aerial view of Caofeidian is provided in Figure 7. (3)

Figure 7 – Caofeidian Phase II Aerial View[6]

Emissions Profile

The plant's latest emission regulations and emissions data are given in Table 9. (3)

Table 9 – Caofeidian Phase II Emissions/Water Consumption Performance

Metric	Requirement	Performance in 2019
PM	10 mg/m^3 (6.24 x 10^{-7} lb/ft^3)	1.70 mg/m^3 (1.06 x 10^{-7} lb/ft^3)
SO_X	35 mg/m^3 (2.18 x 10^{-6} lb/ft^3)	15.04 mg/m^3 (9.38 x 10^{-7} lb/ft^3)
NO_X	50 mg/m^3 (3.11 x 10^{-6} lb/ft^3)	24.76 mg/m^3 (1.54 x 10^{-6} lb/ft^3)

[6] Provided by Professor Mao Jianxiong, Tsinghua University (3)

Huaibei Shenergy Power Generation's Pingshan II

Distinguishing Features

Huaibei Shenergy Power Generation's Pingshan II ("Pingshan II") is a nameplate-rated 1,350-MW USC power plant in Pingshan, Anhui Province, PRC. General Electric (GE) signed a contract with Shanghai Boiler Works to supply its first SteamH boiler for Pingshan II.

Technical Summary

Pingshan II is an expansion approved in 2017 as a PRC demonstration project with a conventional and elevated turbine layout. The unit is expected to be the most efficient and cleanest coal-fired power unit in the world. The project investment was reported to be approximately US$0.78 billion. This large-scale power plant development was combined under the PRC's energy policy "energy savings & emissions reduction" and is considered one of the world's leading coal-fired HELE technologies. The high-efficiency USC double reheat unit was built on a site reserved during the first-phase project. The environmental protection facilities, such as flue gas denitrification, dust removal and desulfurization, were built simultaneously.

The double-reheat USC configuration will benefit from the full range of highly effective 5E coal plant improvement technologies. The plant will include the first ever implementation of a split-level turbine generator, with elevated high pressure (HP) and intermediate pressure (IP)1 steam turbines. The IP2 and low pressure (LP) turbines are located on the ground level. The five "E" technologies are 1) energy savings, 2) efficiency preservation, 3) environmental protection, 4) ensuring safety, and 5) elevated-turbine generator. The unit's design will allow CO_2 gross emission of 251 g/kWh (0.55 lb/kWh), which is about 15 grams (0.03 lb) lower than the most advanced double-reheat unit in the PRC with a CO_2 emission of 266.2 g/kWh (0.59 lb/kWh).

The plant's equipment and service providers are given in Table 10; its operating parameters are given in Table 11.

Table 10 – Pingshan II Equipment and Service Providers

Contribution	Contributor
Engineering, Procurement & Construction	Shanghai Electric Power Construction Corporation (boiler), Anhui Electric Power Construction Corporation (turbine)
Operator	Shenergy
Boiler	Shanghai Boiler Works
Steam Turbine	GE
Generator	GE

Table 11 – Pingshan II Operating Parameters

Plant Name	Pingshan II Power Plant
Location	Pingshan, Anhui Province, PRC
Online Date	Planned 2021 (4)
Nameplate Capacity	1,350 MW
Coal Type	Hard Coal
Efficiency	49.8% LHV
Elevation	~ 80 meters

Pingshan II's boiler steam conditions are given in Table 12; Pingshan II's turbine generator is supplied by GE—no other details are publicly available.

Table 12 – Pingshan II Steam Conditions

Steam Conditions (BMCR)	
Main Steam Flow Rate	958 kg/s (2,112 lb/s)
Main Steam Temperature	610 °C (1130 °F)
Main Steam Pressure	32.5 MPa (4,714 psi)
First Reheat Steam Flow Rate	0.9050
First Reheat Steam Temperature	630 °C (1166 °F)
First Reheat Steam Pressure	9.65 MPa (1,400 psi)
Second Reheat Steam Flow Rate	0.7818
Second Reheat Steam Temperature	623 °C (1153 °F)
Second Reheat Steam Pressure	2.29 MPa (332 psi)
Condensate Temperature	19 °C (66 °F)
Condensate Pressure	4.0 kPa (0.6 psi)

The first steam reheat loop and second reheat loop are to be introduced to increase the electrical efficiency. However, the reheat loops require additional boiler and turbine components, which will raise capital costs. For a 1,000-MW single-reheat unit, the pipelines can be up to 200-m (656-ft) long. In the double-reheat system, the steam travels twice as far, which further increases the flow resistance and heat losses for the second reheat. Additionally, the steam in the pipe increases the thermal inertia, which slows the turbine load adjustment. Arranging these large diameter thick-wall pipes is difficult.

There are innovations to the system to reduce heat loss, which further improves efficiency. The re-design is known as the cross compound with elevated and conventional layout, referred to as elevated turbine generator unit. In this arrangement, the turbines are spilt into two trains. The front train, consisting of the HP turbine and IP turbine (IP1 in Figure 8 and Figure 9) coaxial with one generator as the front unit. The unit is to be mounted on top of a two-pass boiler or near the outlets of the tower type boilers headers, which is around 80–85 m (262–279 ft) above ground level. The rear train, which consists of the IP2 and the two LP turbines coaxial with another generator as the rear unit, is to remain in the conventional position, roughly 17 m (56 ft) above ground level. By raising the HP turbine to the level of the boiler steam header, the following are to be minimized and shortened: 1) main steam pipe, 2) cold reheat steam pipe I, 3) hot reheat pipe I, and 4) cold reheat steam pipe II. The shorter pipework is to reduce the pressure drop and temperature loss of steam from the boiler, which increases efficiency. Further, the cost of the piping is to be significantly reduced.

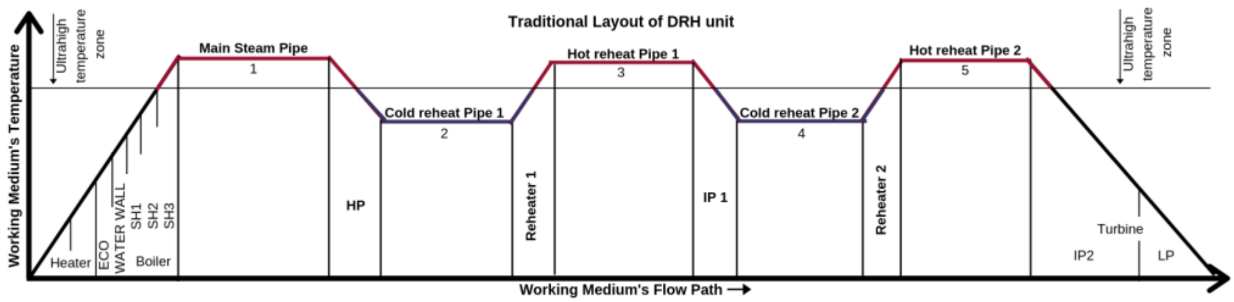

Figure 8 – Pingshan II Steam Flow Path and Temperature, Conventional Double Reheat Configuration[7]

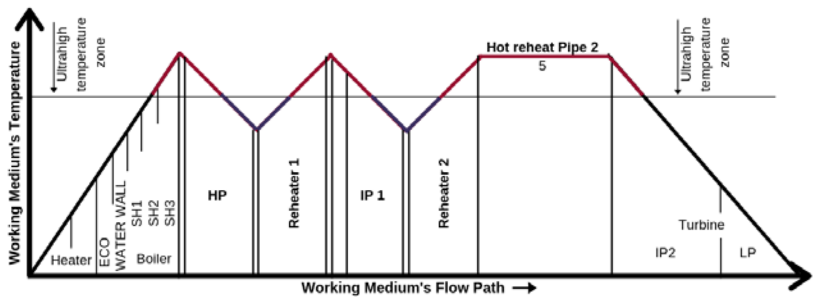

Figure 9 – Pingshan II Steam Flow Path and Temperature, Double Reheat with Feng Split-Level Turbine Generator, Elevated HP/IP1 Turbine[8]

Generalized regeneration technologies and other energy-saving technologies are used to expand the regenerative cycle from a single feedwater-based system to the whole unit, including water, air, and coal to reduce turbine exhaust losses during the whole operating-load condition, load-changing condition, seasonally adapted operation, and solid particle erosion (SPE).

To ensure steady combustion under low load, on the turbine side, the feedwater temperature is to be kept at the rated level by adding an adjustable valve on the extraction pipe to keep the outlet pressure constant. On the boiler side, low-oxygen and low-NO_X combustion technologies are to be used over the whole load range. For auxiliary facilities, the generalized variable frequency power system will be applied. To respond fast to requests from the power grid, the governor valve of the turbine is to be generally throttled to retain a certain degree of thermal storage capacity. Changing the turbine load by a combination of condensate water frequency control and adjustable LP and HP steam extraction frequency control can eliminate throttling losses. A technology that switches off the LP turbine in the summer has been developed but will not be used at Pingshan II due to the late application. The SPE problem was solved using the solution developed at the Waigaoqiao III power plant.

The boiler design for Pingshan II was a collaboration with GE based on the experiences of Pingshan I. Pingshan II's steam temperatures are 610/630/623°C. For the highest temperature tubes, Super 304H, HR3C, and Sanicro-25 stainless steels are used, and P92 steel is used for the headers and pipes.

GE supplied most of the key components of the boiler including burners, waterwall, and superheaters and reheaters, and worked with Shanghai Electric Co. to supply the complete boiler.

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[7] Used with permission from IEA Clean Coal Centre, now International Centre for Sustainable Carbon, an IEA Technology Collaboration Programme (35)
[8] Ibid.

PRC's National Energy Administration approved its technical evaluation and authorized a domestic demonstration project for the technology in 2015. The Shanghai government did not approve it due to its coal-control policy, so it landed in Pingshan, Anhui Province. The project passed its overall final approval on December 28, 2016, and construction started in 2017. Upon achieving commercial operation, Pingshan II is expected to be the most efficient and cleanest plant in the world.

Emissions Profile

The main fuel for the boiler is hard coal and the unit's specifications are detailed in Table 13 along with future technology improvements.

Table 13 – Pingshan II's Specifications and Future Technology

Fuel Specifications	Design Condition		Annual Average Load Rate at 80%	
	Elevated T-G unit with 600 °C (1112 °F) Main Steam Temp.	Future Elevated T-G unit with 700 °C (1292 °F) Main Steam Temp.	Elevated T-G unit with 600 °C (1112 °F) Main Steam Temp.	Future Elevated T-G unit with 700 °C (1292 °F) Main Steam Temp.
Annual Average Coal Consumption Rate	246.7 g/kWh (0.54 lb/kWh)	231.8 g/kWh (0.51 lb/kWh)	251.7 g/kWh (0.55 lb/kWh)	236.2 g/kWh (0.52 lb/kWh)
Annual Average Net Efficiency, LHV	49.8%	53.0%	48.8%	52.0%
Heat Rate	6,897 kJ/kWh (6,537 Btu/kWh)	6,621 kJ/kWh (6,275 Btu/kWh)	7,377 kJ/kWh (6,992 Btu/kWh)	6,923 kJ/kWh (6,562 Btu/kWh)
Annual Average CO_2 Emissions (Gross)	622.7 g/kWh (1.37 lb/kWh)	588.2 g/kWh (1.30 lb/kWh)	635.4 g/kWh (1.40 lb/kWh)	599.5 g/kWh (1.32 lb/kWh)
Annual Average CO_2 Emissions (Net)	666.0 g/kWh (1.47 lb/kWh)	625.7 g/kWh (1.38 lb/kWh)	679.6 g/kWh (1.50 lb/kWh)	637.8 g/kWh (1.41 lb/kWh)

Taizhou Power Plant

Distinguishing Features

Taizhou Power Plant ("Taizhou") is a USC, 4,000-MW coal-fired power station in Taizhou, Jiangsu Province, PRC. The first two coal-fired units (Phase I: Unit 1 and Unit 2), totaling 2,000 MW, were brought online between 2007 and 2009. The plant was originally owned by China Guodian Corporation. The double-reheat 1000-MW USC units (Phase II: Unit 3 and Unit 4) have been in operation since September 2015 and January 2016, respectively. Both units were domestically designed, manufactured, and erected. It has reached an efficiency of 46.08 percent (net LHV). Emissions are low: PM, 2.3 mg/m^3 (1.44×10^{-7} lb/ft^3); SO_2, 15 mg/m^3 (9.36×10^{-7} lb/ft^3); and NO_X, 31 mg/m^3 (1.93×10^{-6} lb/ft^3). Every Chinese coal power plant is equipped with PM and SO_2 control, and almost all have secondary NO_X removal devices, such as SCR or selective non-catalytic reduction (SNCR). By 2020, all Chinese coal-fired plants have to be upgrades to have ultra-low emissions.

Technical Summary

On August 28, 2017, the PRC's State-owned Assets Supervision and Administration Commission under the State Council announced that China Guodian Corporation and Shenhua Group would be jointly restructured, with the Shenhua Group becoming the China National Energy Investment Group, which would absorb China Guodian Corporation. The merger was completed on November 28, 2017. It is the largest power company in the world by installed capacity, as well as the world's largest coal producer.

Compared to the widely used single-reheat steam cycle—which takes steam exiting from the highest-pressure module in the steam turbine and reheats it in the boiler before releasing it in the second-highest pressure module—double reheat establishes a second reheat loop after the second-highest pressure module before it enters the third-highest pressure module. For example, comparing a 1,000-MW single-reheat system to a 1,000-MW double-reheat unit's thermal efficiency can show a jump by up to two percentage points, meaning that the coal consumption can be reduced by about 14 g/kWh (0.015 lb/kWh). This system has been successfully implemented at the Taizhou Phase II, a USC plant that has five double-reheat units, achieving a power generation efficiency of 46.08 percent.

The plant's equipment and service providers are given in Table 14; its operating parameters are given in Table 15.

Taizhou facility's steam conditions are provided in Table 16.

Unit 3 coal consumption is 266.57 g/kWh (0.57 lb/kWh), which is 6 g/kWh (0.013 lb/kWh) lower than the previous world's best value and around 14 g/kWh (0.031 lb/kWh) lower than the coal consumption of an average single-reheat USC 1000-MW unit. The CO2 emissions of the Taizhou Phase II units are 5 percent lower than those of conventional (single reheat) 1000-MW class USC coal power generating units. Consequently, both units can save a total of 167,300 Mt/year (184,415 tons per year [TPY]) of coal.

Table 14 – Taizhou Equipment and Service Providers

Contribution	Contributor
Sponsor	Guodian Taizhou Power Generation Co., Ltd. (a member of China Guodian Corporation)
Parent Company	China National Energy Investment Group

Table 15 – Taizhou Operating Parameters

Plant Name	Taizhou Power Plant
Location	Taizhou, Jiangsu Province, PRC
Online Date	Phase I (Unit 1 and Unit 2): 2007–2009 Phase II (Unit 3 and Unit 4): 2015 and 2016
Nameplate Capacity	Phase I (Unit 1 and Unit 2): 2000 MW Phase II (Unit 3 and Unit 4): 2000 MW
Coal Type	Bituminous Coal
Efficiency	46.08% (LHV)
SO_X	15 mg/m^3 (9.36 x 10^{-7} lb/ft^3)
NO_X	31 mg/m^3 (1.93 x 10^{-6} lb/ft^3)
PM	2.3 mg/m^3 (1.44 x 10^{-7} lb/ft^3)

Table 16 – Taizhou Steam Conditions

Steam Conditions	
Main Steam Flow Rate	753 kg/s (1,660 lb/s)
Main Steam Temperature	600 °C (1112 °F)
Main Steam Pressure	31 MPa (4496 psi)
Reheat Steam Flow Rate	0.886/0.7674
Reheat Steam Temperature	610/610 °C (1130/1130 °F)
Reheat Steam Pressure	10.5/3.2 MPa (1,523/464 psi)
Feedwater Temperature	315

Emissions Profile

The plant's environmental performance is summarized in Table 17.

Table 17 – Taizhou Emissions/Water Consumption Performance

Metric	Performance
PM	2.3 mg/m^3 (1.44 x 10^{-7} lb/ft^3)
SO_X	15 mg/m^3 (9.36 x 10^{-7} lb/ft^3)
NO_X	31 mg/m^3 (1.93 x 10^{-6} lb/ft^3)

Waigaoqiao Power Station Phase III Units (7-8)

Distinguishing Features

The 5,000-MW Waigaoqiao Power Station shares the distinction of being one of the PRC's largest thermal power plant projects with the similar capacity of Guodian Beilun power station in Zhejing. The plant currently accounts for about one-third of Shanghai's total installed base. Waigaoqiao Power Station Phase III Units (7-8) ("Waigaoqiao Phase III") are USC units in Pudong, Shanghai, PRC. The design coal for the plant is sourced from the Shenfu Dongsheng coal field located in Inner Mongolia.

East China Electric Power Design Institute was in charge of the plant design, and Shanghai Power Construction Corporation was responsible for the construction. The boilers and turbine/generators were manufactured and supplied by Shanghai Electric under license of Alstom and Siemens, respectively. Siemens provided main components for two steam turbines, one electric generator for the plant, and its SPPA-T3000 instrumentation and control system.

Technical Summary

Waigaoqiao Phase III is owned by the state-run Shenergy Group Company Limited through its subsidiary Shenergy Company Limited. Shenergy Company Limited is also the operator of the power station. Alstom was awarded a contract in July 2012 to conduct a boiler study at Waigaoqiao III to optimize the double reheat steam cycle for higher efficiency. The plant is along the south bank of the Yangtze River, which is the source of water for cooling and servicing requirements of the power station. The water used for boiler service is treated through clarification-sedimentation, reverse osmosis, and mixed-bed resin demineralization. Power generated from the plant is fed into Shanghai Municipal Electricity Power Company, the electric system of the East China Power Grid through two 500-kV transmission lines.

The Waigaoqiao Phase III power project, which has been operational since 2008, consists of two 1,000-MW USC coal-fired generation units. The plant is originally designed to have a net efficiency of 42.07 percent under rated condition (LHV), i.e., 292 g/kWh for the net coal consumption rate, as it burns coal to produce 600 °C (1112 °F) main steam that passes through the turbines under a pressure up to 27.0 MPa (3,916 psi) to drive the generators. The new plant uses the tower type boilers and dual pressure condensers. Both the units were installed with SCR for NO_X removal as well as FGD equipment for sulfur dioxides (SO_X) removal.

The plant's equipment and service providers are given in Table 18; its operating parameters are given in Table 19.

Table 18 – Waigaoqiao Phase III Equipment and Service Providers

Contribution	Contributor
Design	East China Electric Power Design Institute
Construction	Shanghai Power Construction Corporation
Operator	Shenergy
Boiler	Shanghai Electric under license from Alstom
Steam Turbine	Shanghai Electric under license from Siemens
Generator	Shanghai Electric under license from Siemens

Table 19 – Waigaoqiao Phase III Operating Parameters

Plant Name	Waigaoqiao Phase III
Location	Pudong, Shanghai, PRC
Online Date	2008
Nameplate Capacity	1,000 MW per Unit
Coal Type	Bituminous Coal
Efficiency	43.5% (5)
SO_X	15.55 mg/m^3 (9.70 x 10-7 lb/ft^3)
NO_X	16.89 mg/m^3 (1.05 x 10-6 lb/ft^3)
PM	2.17 mg/m^3 (1.35 x 10-7 lb/ft^3)
Elevation	127.56 m (418.5 ft)
Dry Bulb Temperature	16 °C (60.8 °F)
Relative Humidity	79%

Steam conditions are provided in Table 20; a view of the turbine is shown in Figure 10.

Table 20 – Waigaoqiao Phase III Steam Conditions

Steam Conditions (BMCR)	
Maximum Continuous Evaporation	821 kg/s (1,810 lb/s)
Main Steam Temperature	605 °C (1,121 °F)
Main Steam Pressure	28 MPa (4,061 psi)
First Reheat Steam Flow Rate	0.8267
First Reheat Steam Temperature	603 °C (1,117 °F)
First Reheat Steam Pressure	6.3 MPa (928 psi)
Feedwater Temperature	298 °C (568 °F)

Generalized regeneration technologies were used at Waigaoqiao Phase III. The air regeneration system matches extracted steam to the air preheaters to heat the air entering the boiler, which recovers energy from the extracted steam and improves the boiler combustion efficiency. The coal powder regeneration system further dries and heats the coal powder at the outlet of the mills, improving combustion stability and efficiency, especially when high-moisture coal is used. These technologies not only benefit the boiler's combustion and operation but also improve unit efficiency by recovering heat from extractions and reducing heat loss in the condensers.

To improve feedwater regeneration, an additional adjustable HP steam extraction point was added to maintain the final feedwater temperature, or at least minimize the temperature drop, during low-load operation. In addition, the temperature drop of the flue gas downstream of the boiler economizer at low-load conditions can be reduced so that the SCR need not be shut down at low loads. Also, the fast response of the extraction steam pressure by the control valve means that the unit frequency response is faster. The higher air and feedwater temperatures at the waterwall inlet during low operation improve combustion stability and efficiency as well as water dynamics.

Figure 10 – Waigaoqiao Phase III Siemens Steam Turbine[9]

The project team made a commitment to implement the government's call to focus on efficiency improvement, emissions reduction, and technological advancements in power generation. The plant staff and management launched numerous scientific and technological innovation projects and developed a series of new technologies for system optimization and efficiency improvement—from the baseline 42.07 percent efficiency in 2008 to 43.5 percent currently (5); both are annual average net efficiency, much higher than the original design net efficiency under rated load and condition. Plant capacity factors have been 74 percent or higher every year since commissioning. Waigaoqiao III uses 208,650 Mt (230,000 tons) less coal and emits 435,450 Mt (480,000 tons) less CO_2 annually. Emissions of SO_X, NO_X, and PM are well below domestic limits for coal-fired plants, and even below the limits for gas turbine plants.

Waigaoqiao III uses steam to heat up the boiler instead of oil. The boiler is heated by using the following from other processes in the power plant: 1) heated feedwater, 2) evaporated steam from the separator, and 3) hot economizer. This establishes a “hot furnace and hot air” condition before ignition. This approach speeds up startup, reduces auxiliary load, reduces fuel consumption, and reduces emissions. This results in the startup time being less than 2 hours, oil consumption less than 13.6 Mt (14.9 tons), auxiliary loads less than 80 MWh, and coal consumption less than 181.4 Mt (199.9 tons). (6)

Emissions Profile

Faced with severe air pollution, the PRC has the strictest conventional emissions standards for coal-fired power plants in the world. Under this standard, many coal-fired power stations have to spend money on upgrading emissions reduction facilities like FGD, SCR, and ESP; however, they turn out to be a high investment, high energy cost, and high maintenance cost solution. Waigaoqiao Phase III has

[9] Used with permission from Siemens (42)

implemented a series of low-energy-cost and even energy-saving emission reduction technologies to help meet Chinese emissions requirements effectively. For instance, the heat integrated FGD technology compensates for the power consumed by the FGD system by recovering energy from the flue gas heat. Further, a series of technologies contributes to more than 10 years of continuous high efficiency operation of SCR catalyst without replacement. In addition, a small single-digit dust emission density is achieved in an energy-saving manner without any retrofit of the ESP itself. The latest emissions regulations and emissions data are given in Table 21. (6)

Table 21 – Waigaoqiao Phase III Emissions/Water Consumption Performance

Metric	National Requirement	Performance in 2016
PM	10 mg/m^3 (6.24 x 10^{-7} lb/ft^3)	2.17 mg/m^3 (1.35 x 10^{-7} lb/ft^3)
SO_X	35 mg/m^3 (2.18 x 10^{-6} lb/ft^3)	15.55 mg/m^3 (9.70 x 10^{-7} lb/ft^3)
NO_X	50 mg/m^3 (3.11 x 10^{-6} lb/ft^3)	16.89 mg/m^3 (1.05 x 10^{-6} lb/ft^3)

Xuzhou Power Plant – Unit 3

Distinguishing Features

Xuzhou Power Plant – Unit 3 (“Xuzhou”), a subcritical unit in Jiangsu Province, PRC, had a high temperature retrofit, raising the steam temperatures from 538°C (1000°F) to 600°C (1112°F) while keeping the steam pressure unchanged. The retrofit was built from the experience at Pingshan II. The unit was commissioned in mid-2019 and able to achieve an efficiency of 43.5 percent LHV, net basis. This is a significant increase from the previous 38.4 percent LHV basis for a typical 300-MW subcritical unit in the PRC.

Subcritical coal-fired units in the 300-MW capacity range, most of which are younger than 20 years old, still play an important role in the PRC’s power generation. For these 300-MW subcritical units to achieve the annual average efficiency target of 39.6 percent specified, their efficiency under rated conditions needs to be higher than 42 percent, close to the level of early USC units. Potential retrofit options must 1) achieve a significant increase in efficiency, 2) be cost effective, 3) achieve a high return on investment, 4) maintain the increased efficiency over an extend period of time, and 5) be low risk, making use of well-proven materials and equipment.

Technical Summary

Siemens signed an agreement with Shanghai Shenergy Energy Technology Co., Ltd. (“Shenergy Technology”) to implement a high-temperature subcritical upgrade for a 320-MW steam turbine unit at Xuzhou, a subsidiary of CR Power in Jiangsu Province. This will increase the generation revenue of the plant while reducing maintenance costs significantly. Steam temperature is the key factor in influencing the power generation efficiency and coal consumption of a steam turbine. Altering the pressure would require dismantling and completely rebuilding. (7)

The project includes 1) adopting control stage, 2) advanced blade designs, such as 3DS and 3DV, 3) an additional steam extraction for the A0 high-pressure pre-heater, 4) adoption of energy saving measures throughout the plant, and 5) measures to deal with solid particle erosion. This will help CR Power lower the coal consumption of the subcritical unit by more than 10 percent to 287 g/kWh (0.63 lb/kWh), which is close to the USC level. The project will also help reduce performance degradation while improving the unit's flexibility, availability, and reliability. (7)

The overall cost of the retrofits at Xuzhou was approximately US$50 million. Table 22 shows retrofit options that were considered for Chinese 300-MW coal-fired units. The high-temperature retrofit was ultimately chosen as being the most cost effective.

The plant’s equipment and service providers are given in Table 23; its operating parameters are given in Table 24.

Table 22 – Xuzhou Retrofit Options

	Turbine Flow Path Modifications	Upgrade to Double Reheat	Slight Temperature Increase to 566°C	High-Temperature Retrofit
Expected Efficiency Post Retrofit (%)	~ 39.6	~ 41.6 %	~ 40.3%	> 42.3 % (Xuzhou > 42.8%)
Cost Per Unit (US$ million)	8	> 123	36	50
Cost Per % Improvement (US$ million)	~ 10	> 38	~ 19	< 12. 5

Table 23 – Xuzhou Equipment and Service Providers

Contribution	Contributor
Owner	Shanghai Shenergy
Two-Path Drum Boiler	Dongfang Boiler
Turbine	Shanghai Turbine (with Westinghouse Tech.)
Double Reheat Retrofit	Siemens

Table 24 – Xuzhou Operating Parameters

Plant Name	Xuzhou Power Plant – Unit 3
Location	Xuzhou Power Plant- Unit 3, Jiangsu Province, PRC
Online Date	Retrofitted Unit 3: 2019
Nameplate Capacity	Retrofitted Unit 3: 320 MW
Heat Rate	7500 kJ/kWh (7109 Btu/kWh)
Efficiency	43.5% LHV, net

Xuzhou's steam conditions are provided in Table 25.

Table 25 – Xuzhou Steam Conditions

	Steam Conditions Before Retrofit	Steam Conditions After Retrofit
Main Steam Flow Rate	285 kg/s (628 lb/s)	262 kg/s (578 lb/s)
Main Steam Temperature	540°C	603°C
Main Steam Pressure	17.35 MPa(g) (2516 psig)	17.33 MPa(g) (2513 psig)
Reheat Steam Flow Rate	230 kg/s (508 lb/s)	210 kg/s (462 lb/s)
Reheat Steam Temperature	540°C (1004°F)	603°C (1117°F)
Reheat Steam Pressure	3.63 MPa(g) (526 psig)	3.64 MPa(g) (528 psig)

The change of the steam temperature required retrofits that focused on the boiler heating surfaces, primarily the reheaters and radiation superheaters using austenitic steels (Super 304H and Sanicro 25). The piping was also retrofitted with P92 steel. Lastly, the intermediate- and high-pressure steam turbine rotors, blading, sealing, cylinders, and valves were optimized. In addition, to further improve efficiencies, efforts were made to recover heat from flue gas; this reduces the turbine exhaust loss and improves the air preheater performance. (8) With the replacement or modification of the high-temperature parts, the unit can extend its service time to more than 20 years.

Emissions Profile

Before the retrofit, coal consumption was reported at 318 g/kWh (0.70 lb/kWh). After the retrofit, coal consumption reduced to about 287 g/kWh (0.63 lb/kWh). In addition, the upgrade reduced plant's emissions by more than 10 percent and extended the turbine overhaul interval from 6 to 12 years. The retrofit improved the plant's environmental performance and efficiency due to the reduced coal consumption and flue gas mass flow. (8) The environmental performance is summarized in Table 26.

Table 26 – Xuzhou Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	ESP	0.95 mg/m^3 ($6.2x10^{-7}$ lb/ft^3) at 19% load
SO_X	WFGD	3.3 mg/m^3 ($2.1x10^{-7}$ lb/ft^3) at 19% load
NO_X	SCR	28.61 mg/m^3 ($1.8x10^{-6}$ lb/ft^3) at 19% load

Khargone Super Thermal Power Station

Distinguishing Features

Khargone Super Thermal Power Station ("Khargone") is a 1,320-MW coal-fired power station in Selda, Madhya Pradesh, India. Khargone features two USC units of 660-MW capacity each. Additionally, the company said that the new plant will be able to reduce carbon emissions by 3.3 percent. The required facilities for the sustainable running of the plant, such as fuel handling and transportation systems, are also in place.

In April 2015, it was reported that Larsen & Toubro-Sargent & Lundy (L&T-S&L) secured a Rs 5580-crore (55.8 billion rupees, or about US$625 million) turnkey contract from National Thermal Power Corporation Limited for design, engineering, manufacture, supply, erection, and commissioning of the project under USC parameters, a first for India. It is anticipated that manufacturing will take place at Hazira in Gujarat, through joint venture companies with Mitsubishi Hitachi Power Systems (MHPS).

The station was granted environmental clearance on March 31, 2015, with conditions that coal should be delivered by rail, the sulfur and ash content of coal shall not exceed 0.5 percent and 43 percent, respectively, and that satellite imagery shall be submitted annually to monitor alterations of the area.

Technical Summary

The plant is owned by National Thermal Power Corporation Limited, India. L&T-S&L's scope involves complete basic and detail engineering for the entire engineering, procurement, and construction (EPC) on the project. The configuration of the plant is two L&T-MHPS make boilers with side mill arrangement and two L&T-MHPS make steam-turbine generators (STGs). Key technical features involve:

- A design efficiency of 41.5 percent, which is 3.3 percent higher than conventional SC technology
- Single-reheat, once-through, balanced-draft, pulverized coal (PC)-fired SC boilers with vertical water walls and internal rifle tubes that are simpler in construction with lower pressure drop. The Furnace designed for lower slag deposition and lower-NOx fuel-firing system
- STG capacity of 660-MW (265 bar(a)/600 °C [3840 psia/1112 °F] configuration) consisting of one HP, one IP, and two LP cylinders, tandem-compound quadruple exhaust, condensing reheat turbine designed for high operating efficiency, and maximum reliability
- STG auxiliaries like boiler feedwater pumps, condensate extraction pump, condensate polishing unit, LP heater drain pump, cooling water pumps, vacuum pumps, heat-exchangers, etc.
- Deaerator, 5 LP heaters, and double train of 3 HP heaters with topping desuperheater
- Dual-pressure, once-through type condensers with divided water box
- Metallic casing-type cooling water pumps
- Two induced-draft cooling towers
- 275-m (902-ft) high twin flue chimney with a continuous online emission monitoring system
- Solar panels on the roof of some buildings

- Complete balance of plant, raw water intake system, heating, ventilation, and air conditioning system, firefighting system, fuel oil system, ash handling system, coal handling system, water treatment system, cooling water system, effluent treatment system, compressed air, mill reject system, gas-chlorination, tanks, hydrogen generation plant, etc.

The plant's equipment and service providers are given in Table 27; its operating parameters are given in Table 28.

Table 27 – Khargone Equipment and Service Providers

Contribution	Contributor
Owner	National Thermal Power Corporation Limited, India
EPC	L&T-S&L
Boilers	L&T-S&L
STGs	L&T-S&L

Table 28 – Khargone Operating Parameters

Plant Name	Khargone Power Station
Location	Selda, Madhya Pradesh, India
Online Date	Unit 1: August 2019; Unit 2: April 2020
Nameplate Capacity	Unit 1: 660 MW; Unit 2: 660 MW
Coal Type	Blended coal (Indian and imported coal in ratio of 70:30)
Efficiency	41.5% HHV, gross

Khargone steam conditions are provided in Table 29; Khargone's turbine generator is supplied by L&T-S&L—no other details are publicly available.

Table 29 – Khargone Steam Conditions

Steam Conditions	
Main Steam Temperature	600 °C (1112 °F)
Main Steam Pressure	265 bar (3840 psi)

GE Power installed its first turnkey full-flow limestone-based WFGD unit suitable for continuous operation at 500 MW and 100 percent gas flow at the Khargone facility. GE Power's full turnkey basis included design, engineering, manufacturing, testing, civil works, erection, and commissioning. (9)

The plant's water requirement is estimated to be 3,800 m³ per hour, which will be sourced from the Omkareshwar dam on the Narmada River. An effluent management program was implemented to treat all wastewater generated by the plant. The plant plans to reduce and optimize water quantities and effluent generation and is committed to zero discharge. (10)

Emissions Profile

The coal requirement for the project is estimated as 7.65 million Mt/year (8.4 million TPY), much of which will come from the 15-million Mt/year (16.5 million TPY) Pakribarwadih captive coal block. The coal's sulfur and ash contents are expected to be 0.4–0.5 percent and 40–43 percent, respectively. Low-volatile and high-ash coal from the domestic mine will be mixed with higher quality imported grades to fuel the plant. The plant uses a dry-ash extraction system installed with storage facilities to supply ash to the cement industry. There are two ash disposal systems: 1) a conventional wet slurry disposal system with ash water recirculation for the bottom ash and 2) a high-concentration slurry disposal system for the fly ash. (10) The plant's environmental performance is summarized in Table 30.

Table 30 – Khargone Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	ESP	6.46 mg/m^3 (4.03 x 10^{-7} lb/ft^3)
SO_X	Limestone-based WFGD	25 ppm
NO_X	Lower NOx burners with OFA	15 ppm
Hg	Hydrated lime injection; ESP	-

Isogo Thermal Power Station

Distinguishing Features

Isogo Thermal Power Station ("Isogo") is a nameplate rated 1,200-MW, USC facility in Yokohama, Kantō, Japan, burning bituminous coal. Isogo was originally constructed in the late 1960s and with Unit 1 being reconstructed in 2002 and Unit 2 in 2008 based on an anti-pollution agreement with Yokohama City, Isogo. The plant is a compact, urban, coal-fired power station that has simultaneously achieved reduced environmental burden and improved energy efficiency at among the world's highest levels.

The plant uses USC technology to generate steam up to 620 °C (1,148 °F), achieving a thermal efficiency as high as 45 percent (LHV) according to J-POWER, the plant's operator (a wholesale power generator and electric transmission company started by the Japanese government in 1952 and privatized in 2004). In addition, a two-stage combustion system and multi-pollution control technology helps to reduce SO_X, NO_X, and mercury (Hg) pollutants. J-POWER claims these levels are almost the same as those of gas-fired plants.

Technical Summary

J-POWER is owned by Electric Power Development Co., Ltd., which distributes wholesale energy from principally hydroelectric and fossil-fueled plants to 10 utilities across Japan.

Isogo ranks as one of the cleanest coal-fired power plants in the world in terms of emissions intensity, with levels comparable to those from a natural gas-fired combined-cycle plant. (11) The air quality control system (AQCS) on Unit 2 is a multipollutant control system, unlike the individual components found in Unit 1 and in most coal-fired plants. Unit 2 uses Regenerative Activated Coke Technology (ReACT™) supplied by Hamon Research-Cottrell Inc. of the United States to scrub SO_X, NO_X, and Hg from the flue gas.

The plant's operating parameters are given in Table 31 and boiler details are given in Table 32.

Table 31 – Isogo Operating Parameters

Plant Name	Isogo Thermal Power Station
Location	Yokohama, Kantō, Japan
Online Date	Unit 1: April 2002 & Unit 2: July 2009
Nameplate Capacity	Unit 1: 600 MW & Unit 2: 600 MW
Coal Type	Bituminous Coal
Efficiency	45% LHV

Table 32 – Isogo Boiler Details

Type	USC, Tower Type Boiler
Special Features	Generates high-temperature, HP steam
	Impeller blades rotate at high speed by the jet impact and expansion forces
	Steam is cooled with seawater to condense to water prior to return to boiler

Steam conditions are provided in Table 33; Isogo's turbine generator performs at 45 percent (LHV) efficiency—no other details are publicly available.

Table 33 – Isogo Steam Conditions

Steam Conditions	Unit 1	Unit 2
Main Steam Temperature	600 °C (1,112 °F)	600 °C (1,112 °F)
Main Steam Pressure	25 MPa (3,626 psi)	25 MPa (3,626 psi)
Reheat Steam Temperature	620 °C (1,148 °F)	610 °C (1,130 °F)

The main fuel for Isogo is bituminous coal, which is imported from overseas. The port facilities include one coal unloading wharf and one coal ash loading-oil unloading pier. Coal is stored in the coal silos through the conveyors after unloading from the coal ships. The coal is delivered to the pulverizers through coal feeders after the short time storage in the bunkers. The PC is transported into the boiler by hot air. At Isogo, indoor coal/ash silos and air floated belt conveyors are used for storing and handling coal and ash. These systems are sealed, enclosed to prevent the dispersion of soot and dust. Almost the entire amount of coal ash is used to great advantage for fertilizer and for reinforcement of cement.

The plant effluent and general sewage water from the power station is clarified in the general wastewater treatment plant for discharge. The intake and outlet temperature difference for the sea water used for cooling the steam in the condenser is 7 °C (12.6 °F) or less.

All equipment is installed indoors in a low-noise type enclosure to minimize the effect of noise and vibration to the surrounding environment. Consideration was given to the power station landscaping to ensure the building and stack would blend into the surrounding environment. Also, the design, arrangement, and coloring of the power station was considered to enhance the view from the sea and to add harmony to the harbor city.

Emissions Profile

The low levels of air emissions reached by Isogo Unit 2 are according to J-POWER is phenomenal and set a new standard for coal-fired power plant design.

- Flue gas emissions are first treated by an ammonia SCR system for reduction of NO_X before entering the ReACT system. The ReACT system reduces NO_X, SO_X, and removes both elemental and oxidized forms of Hg through adsorption using activated coke.
- An ESP is used to remove soot and dust emissions. The flue gas is then exhausted to the atmosphere through a common 200-m (656-ft) stack.
- Improved plant thermal efficiency reduced the amount of CO_2 released into the atmosphere.

The dry-type flue gas denitrification system uses ammonia injected into the NO_X-containing flue gas, and the gas passes through catalyst beds. The chemical reactions taking place in the presence of the catalyst decompose NO_X contained in the flue gas to nitrogen and water.

At the dry FGD unit, flue gas passes through activated carbon filled in the desulfurization tower to adsorb SO_X. The activated carbon is then sent to the regenerative tower. In the regeneration tower, SO_X is expelled from the activated carbon, which is then sent to the desulfurization tower for reuse. The SO_X expelled from the activated carbon is recovered as a highly concentrated sulfuric acid, which is effectively useable. The plant's environmental performance is summarized in Table 34.

Table 34 – Isogo Emissions/Water Consumption Performance

Metric	Technology	Permit	Inlet to ReACT	Typical Stack Emission
PM	ESP	5 mg/m^3	<100 mg/m^3 downstream of primary ESP	<3 mg/m^3 downstream of secondary ESP
SO_X	Dry-type desulfurization plant	10 ppm	~410 ppm	~1 ppm
NO_X	Ammonia SCR de-NO_X system; dry-type flue gas denitrification system	13 ppm	~20 ppm (after SCR)	~7 ppm
Hg	-		-	<2.5µg/m^3

Taketoyo Thermal Power Plant Unit 5

Distinguishing Features

Taketoyo Thermal Power Plant ("Taketoyo") Unit 5, is a USC unit in Taketoyo, Aichi, Japan. The development plans for Taketoyo Unit 5 will see to the decommissioning and demolishing of existing Unit 2, Unit 3, and Unit 4 and the demolishing of the already decommissioned Unit 1. The plan is to contribute an inexpensive and stable supply of power by replacing the heavy crude oil-fired power facility that has been in use for more than 40 years with a highly efficient coal-fired power facility.

Technical Summary

Chubu Electric Power Co., Inc. ("Chubu") is constructing a new coal-fired 1,070-MW power station at the power station, with commissioning planned in 2022 following beginning of construction in May 2018. As part of an effort to develop eco-friendly and renewable energy, power will also be generated through the co-firing of woody biomass at the facility. Cofiring biomass reduces coal consumption and CO_2 emissions from the plant. The plant also has an experimental commercial solar power facility, called "Mega Solar," consisting of 36,918 solar panels covering an area of 120,000 square meters; the 7.5-MW facility came online on October 30, 2011.

As a high-efficiency coal-fired power plant, Taketoyo Unit 5 supplies electricity stably in the long-term and reduces power generation costs while striving to reduce the burden on the environment by mixing woody biomass into coal as fuel and adopting a high-efficiency exhaust gas-processing device. The scope of the reported US$1.9-billion project included construction of the powerhouse, substation, wet cooling towers, and related facilities; and installation of generators and transformers, along with laying of transmission lines.

Taketoyo's operating parameters are given in Table 35.

Table 35 – Taketoyo Operating Parameters

Plant Name	Taketoyo – Unit 5
Location	Taketoyo, Aichi, Japan
Online Date	Unit 5: Planned March 2022
Nameplate Capacity	Unit 5: 1,070 MW
Coal Type	Bituminous Coal and Woody Biomass
Efficiency	46% LHV
SO_X	25 ppm
NO_X	15 ppm
CO_2	0.758 kg CO_2/kWh (1.67 lb CO_2/kWh)

Taketoyo's facility is shown conceptually in an aerial view in Figure 11.

Figure 11 – Taketoyo Aerial View[10]

Large-scale coal-fired power generation in Japan has been adopting PC-fired boilers and up to around 3 percent only (amount of heat ratio) has been said to be available for biomass co-firing due to limitations on the coal grinding capabilities of coal pulverizers and others. The project intends to make co-firing biomass at high ratios in the same PC-fired boiler as in large-scale coal-fired power generation.

In the case of the Taketoyo's Mega Solar, the facility consists of approximately 39,000 solar cell modules, 30 units of 250 kW-class inverters, eight 1,000 kVA step-up transformers, a 7,100-kVA main transformer, and an 84-kV gas-insulated switchgear.

The timeline of the development of Taketoyo is as follows:

- On February 6, 2015, Chubu submitted preliminary development plans to the Taketoyo Town Council.
- In May 2017, Chubu awarded Sumitomo Heavy Industries, Ltd. (SHI) in partnership with Clyde Bergemann supply contract for DRYCON technology.
- In October 2017, Chubu submitted an environmental impact assessment report to the Minister of Economy, Trade, and Industry and received approval in December 2017.
- Construction started in April 2018 with completion scheduled by March 2022.

Emissions Profile

As the Chubu plant development coincided with the 2015 Paris climate agreement, there were calls to reconsider the new coal power plant. Under Japan's environmental impact assessment law, government approval for a power plant project is based on an examination of its effects on the surrounding environment. The environment ministry first objected to Chubu's plan to replace aging oil-fired units at Taketoyo in 2015, claiming a voluntary plan put forward by Japan's power industry to cut greenhouse gas emissions would not be effective enough. As a result, Chubu said it would mix biomass with coal to reduce CO_2 emissions at the plant. The CO_2 emissions are about 5.69 million Mt CO_2/year (6.27 million TPY) (Table 36).

[10] Used with permission from JERA Co., Inc (41)

Table 36 – Taketoyo Emissions/Water Consumption Performance

Metric	Performance
PM	6.46 mg/m^3 (4.0x10^{-7} lb/ft^3)
SO_X	25 ppm
NO_X	15 ppm
CO_2	5.69 million Mt/yr (6.27 million TPY)

Taean Power Station

Distinguishing Features

Taean Power Station ("Taean") is a 6,100-MW coal-fired power station in Taean, Chungcheongnam-do, Republic of Korea. The plant is one of the ten largest coal plants in the world. In addition, a 300-MW integrated gasification combined cycle (IGCC) power plant is located at the site. The existing power station consists of eight 500-MW units built from 1995 to 2007. The plant burns imported bituminous coals. Taean Unit 9 and Unit 10 consist of two USC coal-fired steam electric power units with a nominal net electric power output of 1,025 MW each. Each unit is equipped with SCR, WFGD, and ESP to reduce emissions. New cyclone desulfurization and dust collection technology was used to reduce fine dust.

Technical Summary

The sliding-pressure, balanced-draft, front/rear PC-fired USC, boiler was provided by Hitachi. The steam cycle includes eight stages of feedwater heating. The Taean IGCC power plant was a major leap forward for Korea Western Power Co. Ltd. (KOWEPO) as a global environmentally friendly energy utility. The IGCC technology uses a HP gasifier to turn coal into synthesis gas. By utilizing combined cycle technology, IGCC has a superior generating efficiency compared to PC-fired technology. By removing the pollutants while in the relatively low-volume syngas rather than in the post-combustion flue gas, an IGCC unit has lower pollutant emissions. In addition to commercializing IGCC technology, KOWEPO investigated the feasibility of coal-base integrated gasification fuel cell (IGFC) technology.

Burns & McDonnell of the United States provided consulting and professional services to KOWEPO/Korea Electric Power Corporation (KEPCO) Engineering & Construction Company, Inc. for the plant, which included bid evaluation support, onshore engineering services in the Republic of Korea, review of major system design criteria, design review, technology transfer and training, and startup management field support. Enhancing the overall power generation efficiency of the entire plant by about 1.5 percent results in reducing 816,467 Mt (900,000 ton) of greenhouse gas emissions and saving 30 billion Korean won (US$25–30 million) on fuel expenses annually.

The plant's equipment and service providers are given in Table 37; its operating parameters are given in Table 38.

Table 37 – Taean Equipment and Service Providers

Contribution	Contributor
Owner	Korea Western Power of Korea Electric Power Corporation
Sponsor	Burns and McDonnell
EPC	Doosan

Table 38 – Taean Operating Parameters

Plant Name	Taean Power Station
Location	Taean, Chungcheongnam-do, Republic of Korea
Online Date	Units 1–8: 1995 to 2007; Unit 9: June 2016; Unit 10: December 2016
Nameplate Capacity	Units 1–8: 500 MW Units 9–10: 1,050 MW
Coal Type	Blending of bituminous coal and subbituminous coal
Efficiency	Estimated to be 44 to 47% LHV, net

Taean's facility is shown below in an aerial view (Figure 12). Steam conditions are provided in Table 39.

Figure 12 – Taean Aerial View[11]

Table 39 – Taean Steam Conditions

Steam Conditions	
Main Steam Temperature	603 °C (1117 °F)
Main Steam Pressure	25.9 MPa (3756 psi)
Reheat Steam Temperature	613 °C (1135 °F)

IGCC Power Plant

The IGCC power plant project was prioritized as the government's Korean-type demonstration plant development project to secure greenhouse gas emissions reduction technology and clean coal utilization technology. This plant was the Korean government's largest coal research project and involved Doosan Heavy Industries, domestic research organizations, and universities, and others. The power plant began to generate power with a natural gas-powered gas turbine in April 2018. After the first ignition of the gasifiers, a comprehensive test run and a legal inspection were completed.

Ecological Study on Benthic Marine Algae

An ecological study of the community structure of benthic marine algae was investigated at Taean and other places around Taean Peninsula, on the west coast of the Republic of Korea. A total of 100 species were identified. 78 species were found at the power plant intake, followed by 61 at the discharge. The average diversity indices were between 0.70 and 1.20 at each area based on their dry weight. The similarity index was 0.79 between the algal flora of this study and that of 1987, indicating that the condition of the benthic environment remained unchanged since then. The area maintained its environmental quality, so the algal community remained the same with similar structure. The study area

[11] Used with permission from Daelim Industrial Co., Ltd. (29)

seemed to be suitable for long-term monitoring of the benthic environment where industrial facilities, such as a power plant, might affect the benthic algal community.

Emissions Profile

The plant environmental parameters are not publicly available.

Samcheok Green Power Station

Distinguishing Features

Samcheok Green Power Station ("Samcheok") is a four-unit, nameplate rated 2,080-MW USC plant in Samcheok, Gangwon-do, Republic of Korea, burning high-moisture Indonesian coal and biomass. The plant utilizes once-through USC circulating fluidized bed (CFB) boilers employing advanced vertical-tube low mass flux Benson evaporator technology, which achieves higher efficiency and is easier to build and maintain than conventional spiral-wound SC boiler systems. The CFBs do not require back-end FGD equipment for SO_X control. The unique low-temperature CFB combustion process coupled with USC steam technology provides high plant efficiency and low emissions. Samcheok also aims to use a range of renewable energy sources at the plant.

Technical Summary

The plant is operated by Korea Southern Power (KOSPO) of KEPCO for Samcheok, Gangwon-do, Republic of Korea. KEPCO reportedly had intentions to expand the plant to 5,000 MW, powered by a mix of coal, biomass, and renewables.

The plant uses CFB technology from Sumitomo SHI Foster Wheeler, with fuel flexibility and design features that make it more reliable than conventional PC technology. The plant is equipped with four CFB boilers in tandem with two STGs. The contract was awarded in 2011 for the design and supply of four 550-MW USC boilers. The boiler configuration consists of Benson-type, vertical-tube furnace; with eight cyclones per boiler, integrated recycle heat exchanger (INTREX) (four superheaters and four reheaters), regenerative air preheater, eight coal silos, and one biomass silo.

The plant's equipment and service providers are given in Table 40; its operating parameters and steam conditions are given in Table 41 and Table 42; and its turbine and generator details are given in Table 43.

Table 40 – Samcheok Equipment and Service Providers

Contribution	Contributor
Owner	KOSPO
Operator	KEPCO
Boiler	Sumitomo SHI Foster Wheeler
Steam Turbine	Toshiba

Table 41 – Samcheok Operating Parameters

Plant Name	Samcheok Green Power Plant
Location	Samcheok, Gangwon-do, Republic of Korea
Online Date	Units 1 & 2 – December 2016; Units 3 & 4 – June 2017
Nameplate Capacity	Gross – 2,200 MW; Net – 2,080 MW
Coal Type	High-moisture Indonesian Coal and Biomass
Heat Rate	8,496 kJ/kWh (8,053 Btu/kWh) LHV/9,285 kJ/kWh (8,800 Btu/kWh) HHV
Efficiency	42.4% LHV/38.8% HHV

Table 42 – Samcheok Steam Conditions

Steam Conditions	
Main Steam Flow Rate	436 kg/s (961 lb/s)
Main Steam Temperature	603 °C (1,117 °F)
Main Steam Pressure	25.7 MPa (3,728 psig)
Reheat Steam Flow Rate	355 kg/s (783 lb/s)
Reheat Steam Temperature	603 °C (1,117 °F)
Reheat Steam Pressure	5.4 MPa (783 psig)
Feedwater Temperature	297 °C (567 °F)

Table 43 – Samcheok Turbine and Generator Details

Supplier	Toshiba
Steam Turbine	1,000-MW Toshiba 48-Inch Last-Stage Blade Turbine
Type	Tandem compound, Reheat, Condensing

CFB technology can use lower-quality, less-costly coal than PC designs, and advancements in the technology offer fuel flexibility and reduced emissions, making a plant both more environmentally friendly and economically viable. The vertical tube boiler design has several advantages over conventional spiral tube designs. There is a lower steam-pressure drop across the boiler, reducing boiler feedwater pump power, which improves plant efficiency. The vertical-tube design avoids the complicated support system needed for spiral-tube boilers, making such boilers easier to build and maintain. This allows the use of many of the same relatively low-cost and low-maintenance materials used in subcritical boilers, except in the final superheater section. Final superheating is done in a high-efficiency fluidized bed heat exchanger—INTREX. This protects the high-temperature superheating coils from the corrosive flue gases in the furnace. This allows for the same SC temperatures to be reached using a lower-grade material than would be needed in a PC boiler. It also means a lower-quality fuel can be used without sacrificing steam temperature or unit reliability.

KOSPO also focuses on water conservation and recycling, securing water for the plant through bank filtration, rainfall purification, and seawater desalination. It recycles all outflows with an integrated water and wastewater treatment system. An intelligent lighting control system uses both natural and light-emitting diodes. The plant also strives for energy efficiency and sustainability across the entire complex. The coal units' stacks are integrated with the plant's office buildings and control room. Excess heat from the stacks is used to heat the office buildings and other buildings on the site. Environment friendly bio-paints were applied to pipes buried under the ground and sea to prevent corrosion.

KOSPO aims to use a range of renewable energy sources at the plant and plans to install 1) wind turbines on the seawall, 2) solar photovoltaic panels on the roofs of buildings and slopes of the site, 3) a small hydropower generator at the drainage canal, 4) wave power generation units at the seawall, and 5) a fuel cell facility that will use gas from Korea Gas Corporation and bog gas to generate power. A center is to be set up within the power plant to research and develop technologies to reduce CO_2 emissions; KOSPO also plans to conduct research into coal gasification.

Emissions Profile

The main fuel for the boiler is high-moisture Indonesian coal and biomass with specifications shown in Table 44. The plant's coal supply is stored in enclosed bunkers and conveyed with closed conveyors to the boilers to reduce fugitive coal dust. There are no above-ground coal piles, or problems with coal dust in the plant's vicinity. The plant also co-fires biomass. The plant has options to procure recycled wood waste from the Republic of Korea's lumber industry or can import pellets from foreign suppliers.

Table 44 – Samcheok Fuel Specifications

Fuel Specifications	Indonesian Coal		Biomass	
	Design Value	Range	Design Value	Range
Fuel Heating Value [LHV, a.r. MJ/kg, (Btu/lb)]	16.3 (7,000)	14.2–24.9 (6,100–10,700)	17.0 (7,300)	15.8–18.0 (6,800–7,750)
Moisture (a.r., %)	33.5	20–43	10.0	5.0–15.0
Ash (a.r., %)	3.76	1.1–15.3	1.0	0.7–5.0
Sulfur (a.r., %)	0.1	0.1–1.0	0.03	0.0–0.16
Chlorine (a.r., %)	< 0.03	< 0.03	< 0.01	< 0.05

Samcheok has tight emission limits and can meet emission targets without FGD. NO_X and SO_X emissions are each guaranteed at 50 ppm. Dust emissions are controlled by ESPs so that PM does not exceed 20 mg/Nm^3 (1.25x10^{-6} lb/scf). CO_2 emissions are estimated at about 800 g/kWh (1.76 lb/kWh), about 25 percent below the typical operating conventional coal plant in the Republic of Korea. The ash from the ash handling system is 100 percent recycled. The bottom ash is used for light aggregate and the fly ash is used for cement. Remaining ash is to be used for mine backfill and there is no need for an ash pond. The plant environmental performance is summarized in Table 45.

Table 45 – Samcheok Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	ESP	< 20 mg/Nm^3 (1.25x10^{-6} lb/scf)
SO_X	-	50 ppm
NO_X	-	50 ppm

Mae Moh Power Plant

Distinguishing Features

Mae Moh Power Plant ("Mae Moh") is a 2,400-MW solid-fuel facility located in the Mae Moh District, Lampang Province, Thailand, consisting of 13 units. Units 1–3 were decommissioned and some of the remaining 10 units that are in operation are scheduled to retire over the next few years. The plant is owned by the Electricity Generating Authority of Thailand (EGAT); they proceeded with a repowering plan for units 4–7 with generator replacements. This new unit made Mae Moh the first lignite-fired power plant in Asia operating with USC conditions. The 600-MW unit will generate electricity with high-environmental performance to meet stringent regulations. This USC unit has lower CO_2 emissions compared with subcritical technology. (12)

Mae Moh can supply up to 50 percent of the electricity in the northern area, 30 percent to the central area, and 20 percent to the northeastern area of Thailand. The repowering plan is in line with the new version of the domestic power development plan (2018–2037) to maintain power security in the northern and upper-central regions.

Technical Summary

Alstom, in consortium with Marubeni Corporation, signed an agreement with EGAT to supply and build the new unit at Mae Moh. The total amount of the contract is €950 million (US$1,074 million, July 2020), with Alstom's share of the contract worth approximately €520 million (US$588 million, July 2020). The contract was carried out on an EPC basis. (13)

Alstom supplied the following state-of-the-art technologies: 1) USC boiler, 2) USC steam turbine and generator, 3) SCR to reduce NOx, 3) WFGD system that sprays limestone for the reduction of sulfur oxides by more than 98 percent, and 4) ESPs designed to capture particulate and dust emissions with an at a reduction of more than 99.9 percent. While existing units at Mae Moh were all originally equipped with subcritical boilers, the new unit will operate at USC conditions, which leads to a higher overall plant efficiency, an improvement of close to 20 percent in the heat rate compared to the current specifications and increased power output, as well as a reduction of more than 20 percent in CO_2 emissions per unit of fuel burned compared to current installations. (13)

The plant's equipment and service providers are given in Table 46; its operating parameters are given in Table 47.

Table 46 – Mae Moh Equipment and Service Providers

Contribution	Contributor
Owner	EGAT
EPC	Consortium of Alstom & Marubeni Corporation
USC Boiler	Alstom
SCR	Alstom
WFGD	Alstom
ESPs	Alstom
STG	Alstom
Civil Engineering Studies	Setec
Environmental and Health Impact Assessment	TEAM Group

Table 47 – Mae Moh Operating Parameters

Plant Name	Mae Moh Power Plant
Location	Mae Moh District, Lampang Province, Thailand
Online Date	Units 1–3: 1978–1981 (Decommissioned); Units 4–7: 1984–1985; Units 8–13: 1989–1995; Replacement Units 4–7: 2019–Present
Nameplate Capacity	Units 1–3: 75 MW each; Units 4–7: 150 MW each; Units 8–13: 300 MW each; Replacement Units 4–7: 600 MW
Coal Type	Lignite

The Mae Moh facility is shown in Figure 13.

Figure 13 – Mae Moh Facility[12]

Alstom tasked Setec with carrying out the basic and detailed civil engineering studies. The period of services of January 2015–January 2018 included turnkey design of the turbine hall (100-m [328.1-ft] long x 35-m [114.8-ft] wide x 35-m [114.8-ft] high) and the foundations of the 36,287-Mt (40,000-ton) boiler and ancillary buildings. Setec conducted dynamic calculations of the foundations for the vibrating equipment, as well as building information modeling (BIM).

Emissions Profile

With the technologies used for this plant, CO_2 emissions and other pollutants are reduced. The power plant's environmental quality control includes real-time data collection. As a result, the plant's fine particulate (PM2.5) emissions are lower than that of other plants in nearby provinces. (12)

[12] Used with permission from EGAT (21)

EGAT is to decommission the operation of its lignite coal mine in the Mae Moh district of Lampang Province. The lignite mine has been the only coal resource for the Mae Moh power plant since 1978. The mine—the largest in Thailand—is also operated by EGAT. Thailand's lignite production has peaked and EGAT is preparing to redevelop some retired power-generating units in line with declining lignite output. The mine's lifespan will end in the next 30 years. (14) Coal from the lignite mine is shown in Figure 14, and the plant's environmental performance is summarized in Table 48.

Figure 14 – Coal from the Lignite Coal Mine[13]

Table 48 – Mae Moh Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	ESP	-
SO_X	WFGD system that sprays limestone for the reduction of SO_X	> 98.0%
NO_X	SCR for the reduction of NOx	> 99.9%

[13] Ibid.

Vinh Tan 4 Thermal Power Plant

Distinguishing Features

Vinh Tan 4 Thermal Power Plant (“Vinh Tan 4”) is an SC unit located in Vinh Tan, Binh Thuan, Viet Nam. Vinh Tan 4 will fire bituminous/sub-bituminous coal procured from Indonesia and Australia. Vinh Tan 4 is one of four power plants planned for development within the Vinh Tan power complex (6,224 MW). The Vinh Tan power complex is set to become the biggest power complex in Viet Nam, generating and supplying adequate electricity for the South-Central region and Southern provinces.

Vinh Tan 4 was originally designed to have a capacity of 1,200 MW (2 X 600 MW) and estimated to cost US$1.62 billion. An expansion project was announced in October 2015 to add a new 600 MW at a cost of approximately US$1.10 billion. The 600-MW coal-fired extension project was announced as a part of Viet Nam’s Power Development Master Plan VII and features among the most urgent investment projects planned for development between 2013 and 2020. It will be located adjacent to the other two units and consist of one boiler, one steam generator, and one turbine unit. The extension will use conventional steam, thermal power, and SC steam to generate power. Vinh Tan 4 will also include a Toshiba STG, which can receive steam at a pressure of more than 240 bar (3480 psi). The introduction of SC technology will enable the plant to generate electricity in a more efficient and eco-friendly manner. The plant will also be equipped with advanced flue gas emission reduction technologies, as well as wastewater treatment to meet both Vietnamese and international criteria for environmental protection initiatives.

Technical Summary

Vietnam Electricity Power Generation Corporation 3 (EVNGENCO 3) is developing the power plant, which will have a combined annual output of 10.8 billion kWh. A consortium comprising Doosan Heavy Industries & Construction, Mitsubishi Corporation, Pacific Corporation, and Power Engineering Consulting Joint Stock Company 2 was awarded the US$1.36 billion EPC contract for the power plant in December 2013. The same consortium also won the EPC contract for the Vinh Tan 4 extension project in March 2016. The Korean Eximbank, the Korea Trade Insurance Corporation, the Japan Bank for International Cooperation (JBIC), and the Nippon Export and Investment Insurance are jointly funding 85 percent of the US$1.36 billion EPC contract for the Vinh Tan 4 power plant. JBIC granted a loan of US$202.9 million for the thermal power plant, while the Bank of Tokyo-Mitsubishi (BTMU) granted US$136 million. JBIC and the BTMU provided funds to EVNGENCO 3 to purchase the main equipment from Mitsubishi and Toshiba for the project.

Vinh Tan 4 will utilize a single reheat USC boiler. Burning the coal mix with air in the boiler generates HP steam, which is transported to the HP turbine. The power generated is transmitted to the Vinh Tan 4 substation via a 1,293-m (4242-ft) long, 500-kV double-circuit transmission line. The main transformers for the first unit were energized July 2016, and for the second unit in December 2016. (15)

The plant’s equipment and service providers are given in Table 49; its operating parameters are given in Table 50.

Table 49 – Vinh Tan 4 Equipment and Service Providers

Contribution	Contributor
Parent Company	CLP Holdings, EVNGENCO 3, and Pacific Group Corporation
Owner	EVNGENCO 3
Owner's Engineer	Power Engineering Consulting Joint Stock Company 3
EPC	Doosan, Mitsubishi, Pacific Corporation, and Power Engineering Consulting Joint Stock Company 2
Steam Turbine and Generator Set	Mitsubishi/Toshiba
Boiler Supply and Site Development	Doosan
Civil Work and Structural Steel Erection Works	Construction Corporation No.1
Plumbing work and boiler building	VINAINCON
Ancillary Equipment	PECC2 and Pacific
Symphony Plus Plant Automation System	ABB

Table 50 – Vinh Tan 4 Operating Parameters

Plant Name	Vinh Tinh Tan 4 Power Plant
Location	Vinh Tan, Binh Thuan, Viet Nam
Online Date	Unit 1: December 2017; Unit 2: June 2018; Unit 3: April 2019
Nameplate Capacity	New Units 1–3: 1,800 MW
Coal Type	Bituminous Coal and Sub-Bituminous

Vinh Tan 4's facility is shown conceptually below in an aerial view that shows the location of key equipment. Steam conditions are provided in Table 51; Vinh Tan 4's turbine generator is supplied by Alstom—no other details are publicly available.

Table 51 – Vinh Tan 4 Steam Conditions

Steam Conditions	
Main Steam Flow Rate	488 kg/s (1075 lb/s)
Main Steam Temperature	568.9 °C (1056 °F)
Main Steam Pressure	25.75 MPa (3735 psi)

Vinh Tan 4 plant will use approximately 2.8 million Mt of coal per year (3.09 million TPY) imported via 100,000-deadweight tonnage ships through the coal jetty. The coal is unloaded and transported to the coal yard by conveyor belts, before being delivered to the bunker bay in the main station building via a bucket wheel stacker/reclaimer.

Emissions Profile

The plant's environmental parameters are not publicly available.

John W. Turk, Jr. Power Plant

Distinguishing Features

Entering commercial operation in December 2012, the John W. Turk, Jr. Power Plant ("Turk") was the first USC facility in the United States. Turk, which has a 600-MW nameplate rating and burns low-sulfur subbituminous coal in a spiral-wound universal pressure-type boiler with separate cylinders for the HP and IP turbines, which have 25 percent more turbine stages compared to a conventional subcritical steam turbine. Different super-alloys for each rotor section were selected to match the exact steam conditions allowing for faster startups. The plant was equipped with then state-of-the-art emissions control technologies, including a SCR system to control NOx emissions, FGD to control SO_2 emissions, a fabric filter baghouse to control PM emissions, and activated carbon injection to control Hg emissions.

Technical Summary

The plant is majority owned (73 percent) by American Electric Power's (AEP) Southwestern Electric Power Company. The plant is co-owned by Arkansas Electric Cooperative Corporation (12 percent), East Texas Electric Cooperative (8 percent), and Oklahoma Municipal Power Authority (7 percent). Commissioning of Turk culminated almost 7 years of legal, regulatory, and construction work to bring the reported US$1.8-billion project to completion.

Instead of having a single turnkey construction company responsible for the entire project, AEP selected contractors and suppliers to build their portion of the plant under separate contracts. AEP also retained responsibility for a portion of the plant's infrastructure development. There were three key contracts: B&W, Alstom Power, and Chicago Bridge and Iron (CB&I) (formerly the Shaw Group).

USC boiler technology was based on the B&W opposed-fired, spiral-wound, universal-pressure, balanced-draft boiler design to burn a low-ash, low-sulfur subbituminous coal from the U.S. Powder River Basin. The boiler is a two-pass arrangement with multi-lead, ribbed-tube, spiral-wound lower furnace; mix transition to the vertical tube upper furnace enclosure; two-pass arrangement pendant heating surface; and the two parallel path gas-biasing horizontal convection pass with reheater, primary superheater, and economizer banks. Stainless steel tubing is used for the superheater and reheater. The high-temperature headers and steam leads are 9 chromium creep strength-enhanced ferritic steel.

The plant's equipment and service providers are given in Table 52; its operating parameters are given in Table 53; and the boiler details are given in Table 54.

Turk's Alstom STF60 is a condensing tandem compound single-reheat, 3,600-revolutions per minute STG set. The Alstom STF60 design includes a four-casing steam turbine with a single-flow HP turbine, a double-flow IP turbine, and two double-flow downward exhaust LP turbines. Steam turbine and generator details are shown in Table 55.

Table 52 – Turk Equipment and Service Providers

Contribution	Contributor
Owner's Engineer	American Electric Power Service Corporation
Plant Engineering and Design	CB&I
Plant Construction	CB&I
Steam Generator	The Babcock & Wilcox Co.
Steam Generator Erection	The Babcock & Wilcox Co.
Steam Turbine Generator	Alstom Power
Steam Turbine Generator Erection	CB&I
Selective Catalytic Reduction System	The Babcock & Wilcox Co./Johnson Matthey
Fabric Filter	The Babcock & Wilcox Co.
Dry Flue Gas Desulfurization (Spray Dry Absorber)	The Babcock & Wilcox Co.
Distributed Control System	Emerson Process Management
Sootblowers and Furnace Wall Cleaning	Diamond Power Co.
Cooling Tower	SPX
Condenser	Yuba
Feedwater Heaters	TEI
Circulating Water Pumps	Flygt
Condensate Pumps	Flowserv Corp.
Boiler Feedwater Pumps	Flowserv Corp.
Fuel Handling	Roberts & Schaefer
Auxiliary Transformers	ABB
Large Power Transformers	ABB and VT
Fly Ash Handling	United Conveyor Corp.
Bottom Ash Handling Submerged Flight Conveyor	United Conveyor Corp.
Pebble Lime Preparation	Chemco/Magaldi Ash Cooler
Forced and Induced Draft Fans	Howden
Primary Air Fans	Process Barron
Rail Car Dumper	Heyl and Patterson
Water Treatment	Siemens
Stack	Commonwealth Dynamics Inc.
Auxiliary Boiler	The Babcock & Wilcox Co.

Table 53 – Turk Operating Parameters

Plant Name	John W. Turk Jr. Power Plant
Location	Fulton, Arkansas, United States
Online Date	December 2012
Nameplate Capacity	600 MW
Coal Type	Subbituminous Coal
Heat Rate	9,000 kJ/kWh (8,530 Btu/kWh)
Efficiency	40% (at 9,000 kJ/kWh)

Table 54 – Turk Boiler Details

Supplier	B&W
Type	USC opposed-fired, spiral-wound universal pressure balanced boiler design
Special Features	Two-pass arrangement with multi-lead
	Ribbed-tube
	Spiral-wound lower furnace
	Stainless-steel tubing for superheater and reheater

Table 55 – Turk Turbine and Generator Details

Steam Conditions	
Steam Turbine	STF60
Type	tandem compound
Sections	4 (1 HP, 1 IP, 2 LP)
Main Steam Flow Rate	557 kg/s (1,227 lb/s)
Main Steam Temperature	599 °C (1,110 °F)
Main Steam Pressure	24.1 MPa (3,500 psig)
Reheat Steam Temperature	607 °C (1,125 °F)
Reheat Steam Pressure	5.1 MPa (736 psig)
Feedwater Temperature	299 °C (570 °F)
Turbine Backpressure	10 kPa (1.5 psia)

Turk was designed with eight heaters to raise the final feedwater temperature to improve efficiency as compared with a traditional subcritical unit utilizing six to seven heaters. Four stages of LP condensate heaters, one deaerator, and three stages of HP feedwater heaters are used. An extraction from the HP turbine feeds the top heater, thus the cycle is a heater above the reheat pressure (HARP) design. The advantage of the HARP cycle is that is allows optimizing the final feedwater heater temperature independent of the reheater pressure, which reduces moisture at the LP exhaust. Turk uses a 100-percent single-flow boiler feedwater pump turbine that is fully integrated into the main steam systems. The entire steam system is controlled by an Alstom digital control system. A motor-driven boiler feedwater pump is employed for unit startup that has a nominal capacity of 30 percent.

Emissions Profile

Air quality control systems at Turk include

- Low-NO_X burners with close-coupled over-fire air (OFA) to control primary NO_X emissions
- A post-combustion SCR system to control NO_X emissions
- Dry FGD system to control SO_X emissions
- Pulse-jet fabric filter (PJFF) for PM control
- Activated carbon injection to reduce Hg emissions

The permitted performance requirements of select criteria pollutants are shown in Table 56. The SO_X limit is met using two 50-percent spray dryer absorber (SDA) vessels. Flue gas enters at approximately 135 °C (275 °F) through the roof and the central gas disperses. The rotary atomizer distributes a mixture of fresh lime and recycles slurries. SDA vessels provides a minimum of 12 seconds residence time for drying. The dry flue gas then leaves the SDA at approximately 77 °C (170 °F) and enters the PJFF baghouse. The PJFF baghouse has ten compartments and requires only nine to be in service. There are 12,400 bags, which can be changed while the unit is in service. The residual SO_2, fly ash, and SDA wastes are removed from the bags by individual dry-air pulses, collected in hoppers, and then sent to either the waste silo or recycle slurry process.

Table 56 – Turk Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	PJFF baghouse	-
SO_X	SDA	0.028 kg/GJ (0.065 lb/million Btu) permit limit
NO_X	Low-NO_X burners with overfire air; SCR	-
Hg	Baghouse; SDA	0.52 kg/GJ (1.2 lb/million Btu) permit limit
CO	-	0.064 kg/GJ (0.15 lb/million Btu) permit limit

Longview Power Plant

Distinguishing Features

Longview Power Plant ("Longview") is an 807.5-MW SC coal facility in Maidsville, West Virginia, United States. Longview embodied several firsts at its commissioning: it was the first SC coal plant built in the United States by an independent power producer, the first coal-fired power plant built in West Virginia in 18 years, the first greenfield coal plant in the northeastern United States in 20 years, the first major private equity participation in a new U.S. coal plant project, and the first Siemens steam reference plant in the United States. Also, it was among the first SC PC units in the world to employ a low-mass flux Benson vertical boiler.

Technical Summary

The plant, which is owned by Longview Power, LLC, an independent power producer, was built in partnership with management and private equity firm First Reserve. Construction was by a consortium of Siemens Power and Aker Kvaerner Songer Inc. for a reported US$2.1 billion.

Longview was designed to maximize efficiency and minimize environmental impacts. Foster Wheeler's Benson boiler technology, under license from Siemens, is a once-through (non-recirculating) design that utilizes a low-mass flux boiler and provides full variable furnace and superheater pressure for cycling operation. Vertical evaporator tube-wall construction simplified erection and maintenance and made ash deposit removal easier, which improved plant flexibility by reducing startup time. Equal pressure drop across all tubes in the low-flux design results in more flow (and therefore, more cooling) to tubes that receive more heat, as opposed to high-mass flux designs. The self-compensation for heat variations among tubes eliminates the need for custom orificing and the low-flux design minimizes pressure loss and auxiliary power consumption. Hence, design and construction costs for these plants are reduced and overall efficiency is increased.

Longview's equipment and service providers are given in Table 57; its operating parameters are given in Table 58.

Table 57 – Longview Equipment and Service Providers

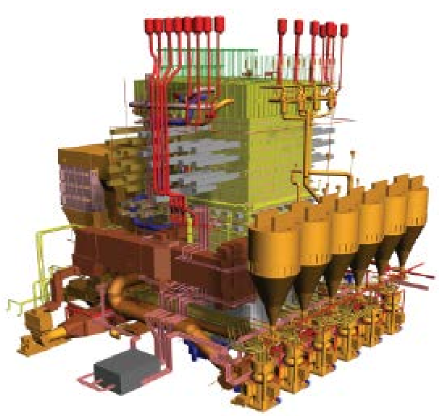
Contribution	Contributor
Construction	Siemens Energy/Aker Kvaerner Songer
Fuel feed	Longview Power, LLC
Boiler	Foster Wheeler
Turbine	Siemens
Generator	Siemens
DCS	Siemens
AQCS	Siemens/(rehab) Foster Wheeler
Owner's Engineer	(rehab) Black & Veatch
Sootblowing	(rehab) B&W
Bottom Ash	(rehab) Foster Wheeler, Howden

Table 58 – Longview Operating Parameters

Plant Name	Longview Power Plant
Location	Maidsville, West Virginia, United States
Online Date	December 2011
Nameplate Capacity	807.5 MW
Nameplate Power Factor	0.98
Coal Type	Appalachian bituminous
Heat Rate	9,329 kJ/kWh (8,842 Btu/kWh)
Efficiency	39% (at 9,232 kJ/kWh [8,750 Btu/kWh])
SO_X	> 99.5% removal
NO_X	Low NO_X
PM	> 99% removal; < 93% permitted
Hg	< 85% permitted; MATS* compliant
CO_2	20% reduction from average coal plant
Elevation	340 m (1,115 ft)
Design Air Pressure	0.97 bar (14.1 psia)
Dry Bulb Temperature	17.2 °C (63 °F)
Wet Bulb Temperature	13.9 °C (57 °F)
Relative Humidity	70%

*Mercury and Air Toxic Standards (16)

Longview's boiler is shown conceptually below with a dimensional projection (Figure 15) and a sideview (Figure 16) that shows the location of key equipment.



Supplier	**Foster Wheeler – boiler details**
Type	**Supercritical Benson (once-through) vertical PC**
Special Features	**Low mass flux**
	Overfire air
	Combustion air measurement scheme (2015 rehab)
	Intelligent soot-blowing optimization (2015 rehab)

Figure 15 – Longview Boiler and Details[14]

[1414] Used with permission from BHI Foster Wheeler Corporation (51)

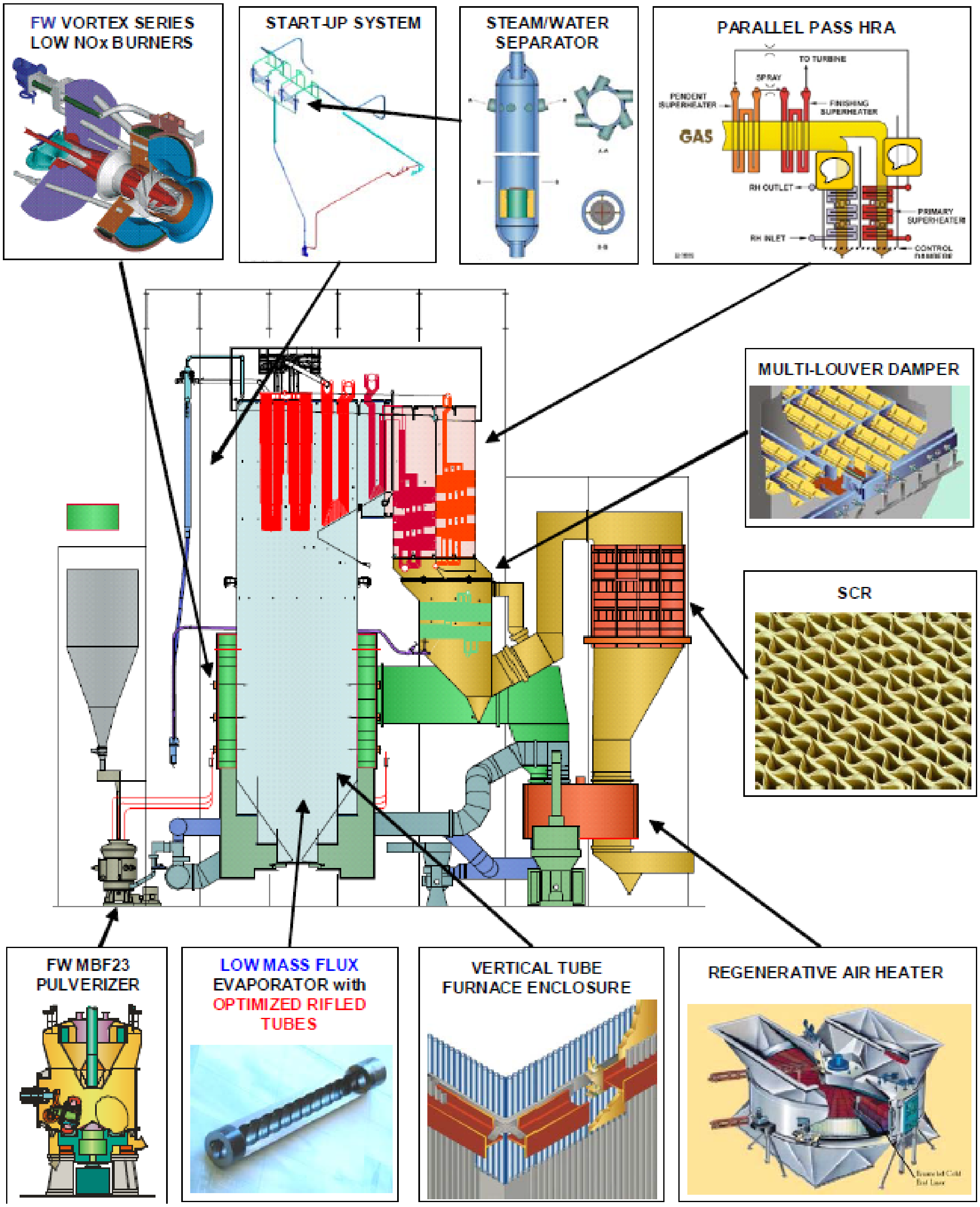


Figure 16 – Longview Boiler Side Elevation[15]

[15] Ibid.

Longview's Siemens HMNN 770-MW steam turbine and S-Gen6 3000-W generator set were designed for high efficiency (Figure 17). The generator is hydrogen- and water-cooled to reduce friction losses and improve heat transfer, achieving up to 99 percent efficiency. The steam turbine uses a tandem-compound arrangement with an HP section, an IP section, and two LP sections, connected directly to the inline generator. The steam conditions are provided in Table 59.

Figure 17 – Longview Turbine and Generator Set[16]

Table 59 – Longview Turbine and Generator Details

Supplier	Siemens
Steam Turbine	HMNN 770 MW
Type	tandem compound
Sections	4 (1 HP, 1 IP, 2 LP)
HP Inlet Temperature	566 °C (1,050 °F)
Inlet Pressure	24.8 MPa (3600 psi)
Generator	S-Gen6 3000W
Cooling	hydrogen; water
Efficiency	≤99%

Longview's Siemens AQCS and water management processes were similarly designed to provide state-of-the-art performance.

[16] Used with permission from Longview (30)

In addition to the efficiency gains for the SC plant, its location near the mouth of a coal mine under the same ownership and fed by a 7.2-km (4.5-mile) conveyor, constituted further economic advantages with reducing the environmental impacts of coal transport. Natural gas for startup and up to 20 percent co-firing capability is provided by a pipeline from a local gas utility, backed up by the world's largest mobile liquefied natural gas storage facility in case of demand-based restrictions on supply.

Several issues initially kept the plant from delivering its promised efficiency and reliability. A subsequent rehabilitation project addressed all known problems, but three aspects stand out for their scope of work and effect:

- Over a thousand boiler tubes made of T23 alloy, instead using T22 overlaid with Inconel were replaced, which succeeded in addressing problems with overheating in the boiler nose arch.
- The original digital control system (DCS) was replaced by an Emerson Ovation plant-wide system. Most of the 12,000 input/output points were left in place but the hardware controlling the boiler, the renovated AQCS, and the steam turbine was replaced.
- An intelligent sootblowing optimization system (B&W Powerclean NX) was installed to help control slag accumulation and improve unit operations and stability.

Other significant aspects of the rehab include the following:

- Various control measures in the primary coal burners, close-coupled overfire air, and other boundary air ports were implemented to achieve emission control requirements including adjustable burner sleeves and cone dampers, dual series registers, adjustable coal nozzle tips, split flame nozzle design, and careful sizing and location of OFA ports. (17; 18)
- Foster Wheeler expanded the AQCS by about 30 percent to accommodate the higher sulfur content of the coal feed and addressed catalyst handling and ammonia injection control logic. A method was added for removing fines from scrubber liquor.
- Siemens overhauled the generator installation, which had problems with excessive vibration and hydrogen leaking through seals, resulting in as-new performance.
- Longview worked with Foster Wheeler and Howden to design and fabricate simpler, more robust bottom ash equipment to replace that entire system.

Emissions Profile

Since the 2015 rehab, Longview has fulfilled its promise to become the most efficient coal-fired unit in North America. The plant's heat rate of 9,329 kJ/kWh (8,842 Btu/kWh) is nearly 25 percent more efficient than the U.S. fleet average and improves upon that of other SC units (Figure 18).

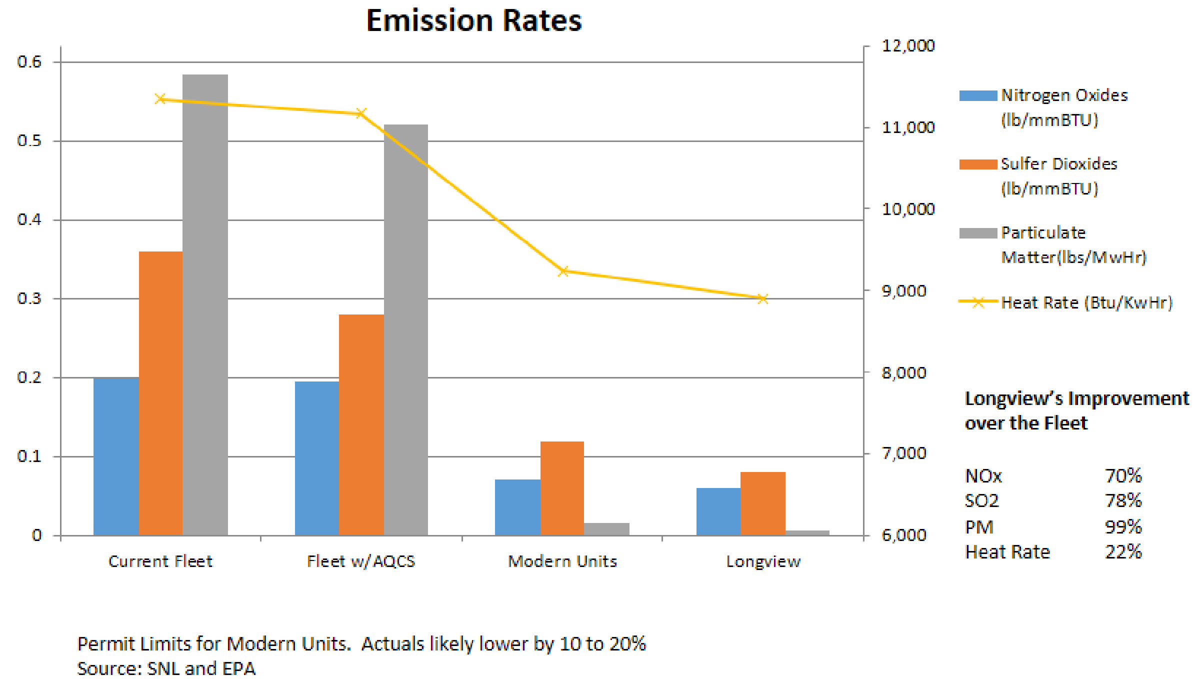


Figure 18 – Longview Emissions and Heat Rate Comparisons (April 2017)[17]

Emissions of NO_X, sulfur oxides SO_X, PM, and Hg are similarly among the lowest in the United States, and CO_2 emissions are about 20 percent below the fleet average. Water consumption is just 0.11 m^3/min (30 gpm) due to a design emphasizing reuse (Table 60). The plant's efficiency and reliability (86 percent capacity factor; 92 percent equivalent availability factor) have led to the lowest dispatch costs in the PJM Interconnection. PJM is a regional transmission organization that coordinates the movement of wholesale electricity in all or parts of 13 U.S. states and the District of Columbia.

Table 60 - Longview Emissions/Water Consumption Performance (2016)

Metric	Technology	Performance
PM	pulse jet fabric filter (baghouse)	> 99% removal (< 93% permitted limit)
SO_X	wet flue gas desulfurization (scrubber)	≤ 99.5% removal 0.03 kg/GJ (0.07 lb/million Btu) (0.041 kg/GJ permitted)
NO_X	low-NO_X burners with close-coupled overfire air; SCR	0.024 kg/GJ (0.055 lb/million Btu) (0.028 kg/GJ permitted)
Hg	hydrated lime injection; baghouse; wet scrubber	< 85% permitted limit 0.0014 kg/GWh (0.0031 lb/GWh) (0.006 kg/GWh permitted) MATS (16) compliant
CO	-	0.013 kg/GJ (0.03 lb/million Btu) (0.047 kg/GJ permitted)
Water Requirements	-	20% < average coal-fired plant
Water Treatment (discharge)	-	21.6 m^3/min (5,700 gpm) (avg)

[17] Ibid.

Virginia City Hybrid Energy Center

Distinguishing Features

Virginia City Hybrid Energy Center (VCHEC) is a 600-MW solid-fuel facility utilizing two CFB boilers that burn coal, up to 20 percent coal waste, and a minimum of 10 percent biomass (per operating permit requirements) provided adequate wood resources are available. Therefore, a percentage of VCHEC's electricity production is considered renewable under the Virginia renewable portfolio standard. The low-emissions CFB combustion system is further supplemented by an AQCS, which includes a dry scrubber, baghouse PM filter, SNCR, and activated carbon injection system to minimize Hg emissions. The facility also features one of the industry's largest air-cooled condenser systems to minimize the plant's water usage. VCHEC approaches zero wastewater discharge.

Technical Summary

The plant is owned by Dominion Virginia Power ("Dominion"). The reported US$1.8-billion project entered commercial operation on July 10, 2012, on budget and on schedule after 4 years of construction. The Shaw Group (now CB&I) served EPC contractor for the project.

VCHEC utilizes two Foster Wheeler fuel-flexible CFB boilers, designed to burn coal, waste coal, and woody biomass. CFB technology combined with modern post-combustion controls has low emissions of SO_2, NO_X, PM, and Hg. The facility operates in an environmentally responsible manner that minimizes overall impact to air, water, and land resources. The CFB's fuel flexibility allows the plant to burn a wide range of regionally available, low-cost waste coals, which helps to clean up the legacy of coal mining. The facility's overall plant heat rate is improved by recycling waste heat from the CFB boiler bed ash system discharge steam to directly preheat the boiler feedwater.

The plant's equipment and service providers are given in Table 61; its operating parameters are given in Table 62.

Table 61 – VCHEC Equipment and Service Providers

Contribution	Contributor
EPC	The Shaw Group (now CB&I)
Owner	Dominion Virginia Power
Boiler	Foster Wheeler
Steam Turbine	Toshiba
Material Handling Systems	Crowder Construction Co.
Chimney Stack	Karrena International
Drilled Caissons	Case Foundation Co.
Final Grading & Paving	WL Foundation

Table 62 – VCHEC Operating Parameters

Plant Name	Virginia City Hybrid Energy Center
Location	Wise County, Virginia, United States
Online Date	July 10, 2012
Nameplate Capacity	600 MW
Coal Type	Coal and Biomass (Wood)

VCHEC's facility is shown conceptually below in a more detailed sideview (Figure 19) that shows the location of key equipment. Steam conditions are provided in Table 63. VCHEC's turbine generator is supplied by Toshiba—no other details are publicly available.

Table 63 – VCHEC Steam Conditions

Steam Conditions	
Main Steam Flow Rate	270 kg/s (595 lb/s)
Main Steam Temperature	568 °C (1,055 °F)
Main Steam Pressure	17.3 MPa (2,515 psig)
Reheat Steam Flow Rate	862,700 kg/h (1,902,000 lb/h)
Reheat Steam Temperature	568 °C (1,055 °F)
Reheat Steam Pressure	4.1 MPa (602 psig)
Feedwater Temperature	255 °C (491 °F)

Emissions Profile

Biomass is a suitable and environmentally responsible fuel source, which meets the Virginia renewable energy goals. The U.S. Environmental Protection Agency ruled that biomass from managed forests will be treated as carbon neutral when used for energy production at stationary sources. (19) This supports the long-term strategy of fuel diversity, creates jobs in the forestry and logistic industries, meets state renewable goals in Virginia and North Carolina, and reduces CO_2 emissions. The plant's environmental performance is summarized in Table 64.

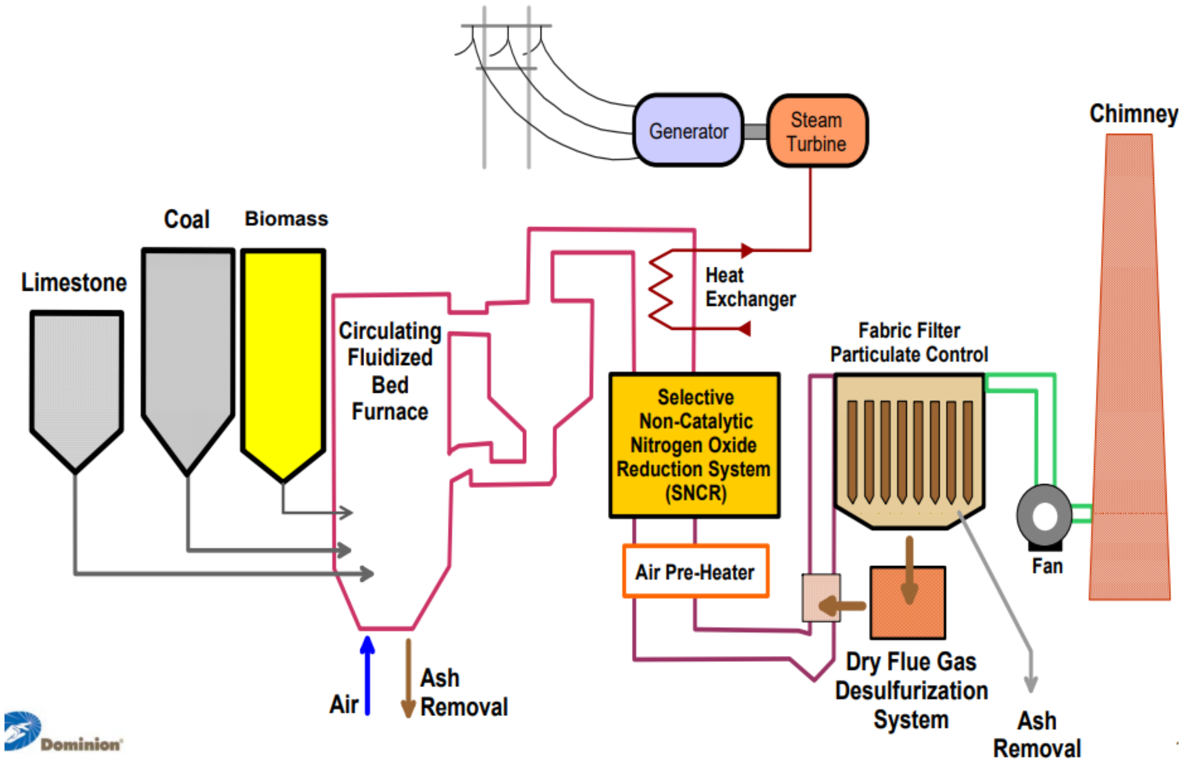


Figure 19 – VCHEC Flow Diagram[18]

Table 64 – VCHEC Emissions/Water Consumption Performance

Metric	Technology	Performance
PM	Fabric filter PM control (baghouse)	299 Mt/year (329 TPY)
SO_X	Dry FGD system (scrubber)	548 Mt/year (604 TPY)
NO_X	Selective non-catalytic nitrogen oxide reduction system	1,742 Mt/year (1,920 TPY)
Hg	Activated carbon injection system; baghouse; dry scrubber	4.5 Mt/year (5 TPY)

[18] Used with permission from Dominion (44)

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