

## Nucla CFB Demonstration Project

**Project completed**

### Participant

Tri-State Generation and Transmission Association, Inc.

### Additional Team Members

Foster Wheeler Energy Corporation\*—technology supplier

Technical Advisory Group (potential users)—cofunder

Electric Power Research Institute (EPRI)—technical consultant

### Location

Nucla, Montrose County, CO (Nucla Station)

### Technology

Foster Wheeler's atmospheric circulating fluidized-bed (ACFB) combustion system

### Plant Capacity/Production

110 MWe (gross), 100 MWe (net)

### Coal

Western bituminous—

Salt Creek, 0.5% sulfur, 17% ash

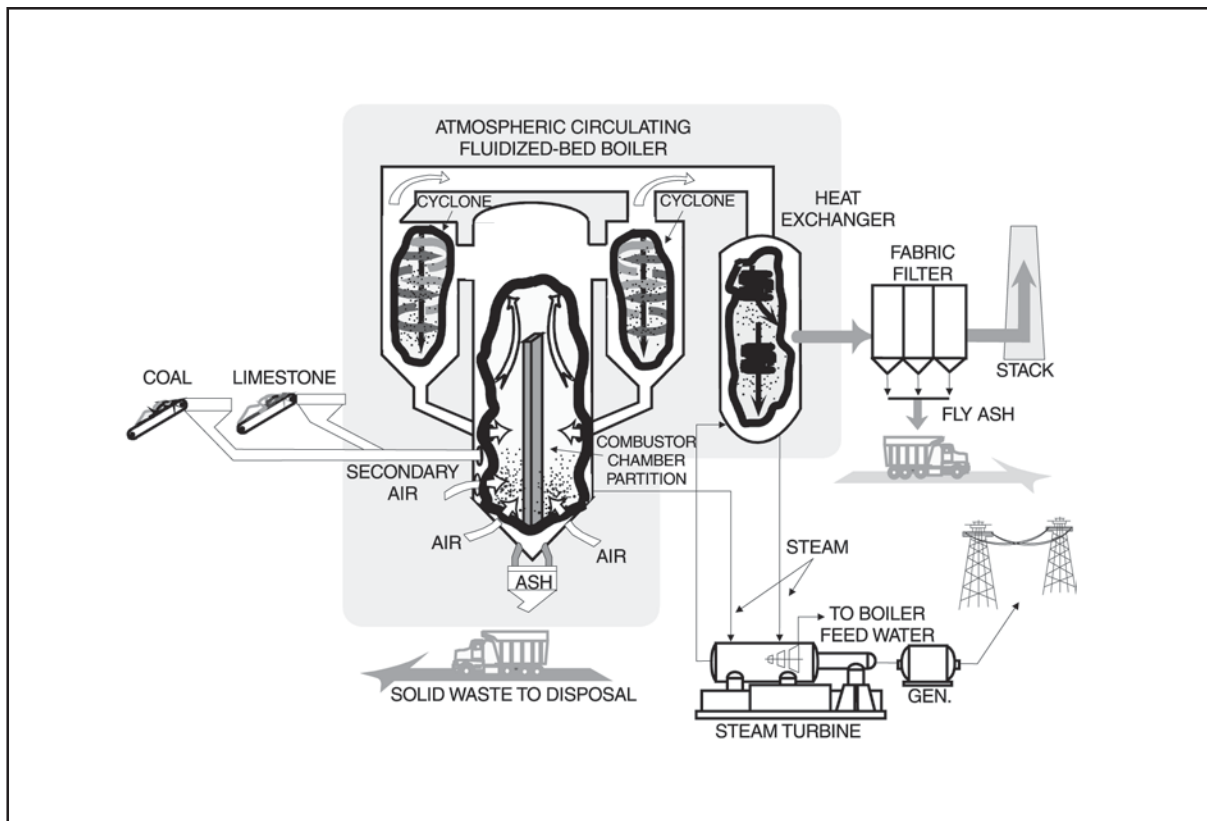
Peabody, 0.7% sulfur, 18% ash

Dorchester, 1.5% sulfur, 23% ash

### Project Funding

Total	\$160,049,949	100%
DOE	17,130,411	11
Participant	142,919,538	89

\* Pyropower Corporation, the original technology developer and supplier, was acquired by Foster Wheeler Energy Corporation.



### Project Objective

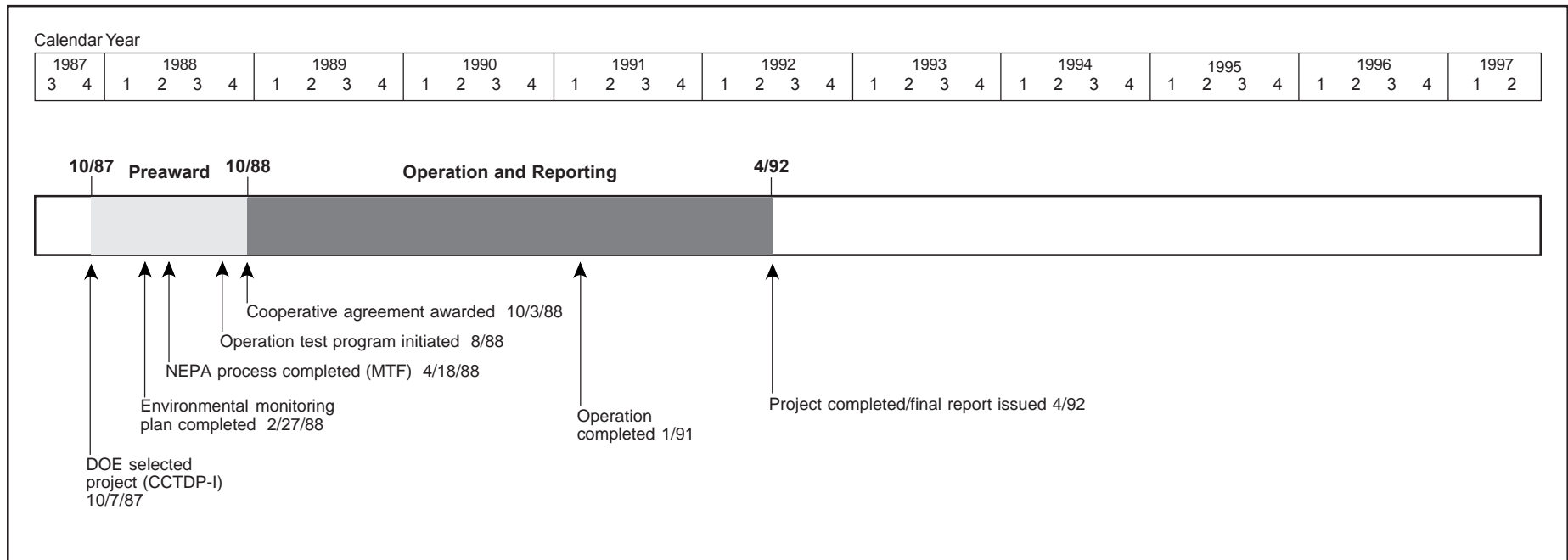
To demonstrate the feasibility of ACFB technology at utility scale and to evaluate the economic, environmental, and operational performance at that scale.

### Technology/Project Description

Nucla's circulating fluidized-bed system operates at atmospheric pressure. In the combustion chamber, a stream of air fluidizes and entrains a bed of coal, coal ash, and sorbent (e.g., limestone). Relatively low combustion temperatures limit  $\text{NO}_x$  formation. Calcium in the sorbent combines with  $\text{SO}_2$  gas to form calcium sulfite and sulfate solids, and solids exit the combustion chamber and flow into a hot cyclone. The cyclone separates the solids from the gases, and the solids are recycled for combustor temperature control. Continuous circulation of coal and sorbent improves mixing and

extends the contact time of solids and gases, thus promoting high utilization of the coal and high sulfur-capture efficiency. Heat in the flue gas exiting the hot cyclone is recovered in the economizer. Flue gas passes through a baghouse where particulate matter is removed. Steam generated in the ACFB is used to produce electric power.

Three small, coal-fired, stoker-type boilers at Nucla Station were replaced with a new 925,000 lb/hr ACFB steam generator capable of driving a new 74-MWe (gross) turbine generator. Extraction steam from this turbine generator powers three existing turbine generators (12.5 MWe gross each).



## Results Summary

### Environmental

- Bed temperature had the greatest effect on pollutant emissions and boiler efficiency.
- At bed temperatures below 1,620 °F, sulfur capture efficiencies of 70% and 95% were achieved at calcium-to-sulfur (Ca/S) molar ratios of 1.5 and 4.0, respectively.
- During all tests, NO<sub>x</sub> emissions averaged 0.18 lb/10<sup>6</sup> Btu and did not exceed 0.34 lb/10<sup>6</sup> Btu.
- CO emissions ranged from 70–140 ppmv.
- Particulate emissions ranged from 0.0072–0.0125 lb/10<sup>6</sup> Btu, corresponding to a removal efficiency of 99.9%.
- Solid waste was essentially benign and showed potential as an agricultural soil amendment, soil/roadbed stabilizer, or landfill cap.

### Operational

- Boiler efficiency ranged from 85.6–88.6% and combustion efficiency ranged from 96.9–98.9%.

- A 3:1 boiler turndown capability was demonstrated.
- Heat rate at full load was 11,600 Btu/kWh and was 12,400 Btu/kWh at half load.

### Economic

- Capital cost for the Nucla retrofit was \$1,123/kW and normalized power production cost was 64 mills/kWh.

## Project Summary

Fluidized-bed combustion evolved from efforts to find a combustion process conducive to controlling pollutant emissions without external controls. Fluidized-bed combustion enables efficient combustion at temperatures of 1,400–1,700 °F, well below the thermal  $\text{NO}_x$  formation temperature (2,500 °F), and enables high  $\text{SO}_2$ -capture efficiency through effective sorbent/flue gas contact. ACFB differs from the more traditional fluid-bed combustion. Rather than submerging a heat exchanger in the fluid bed, which dictates a low fluidization velocity, ACFB uses a relatively high fluidization velocity, which entrains the bed material. Hot cyclones capture and return the solids emerging from the turbulent bed to control temperature, extend the gas/solid contact time, and protect a downstream heat exchanger.

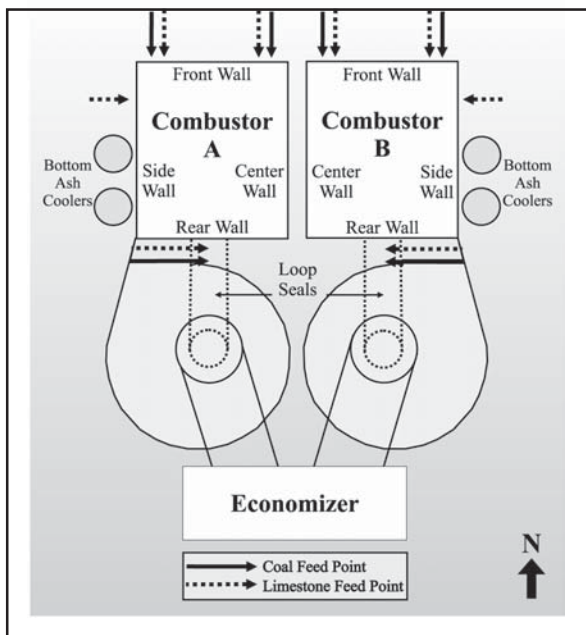
Interest and participation of DOE, EPRI, and the Technical Advisory Group (potential users) resulted in the evaluation of ACFB potential for broad utility application through a comprehensive test program. Over a two-and-a-half-year period, 72 steady-state performance tests were conducted and 15,700 hours logged. The result was a database that remains the most comprehensive available resource on ACFB technology.

### Operational Performance

Between July 1988 and January 1991, the plant operated with an average availability of 58% and an average capacity factor of 40%. However, toward the end of the demonstration, most of the technical problems had been overcome. During the last three months of the demonstration, average availability was 97% and the capacity factor was 66.5%.

Over the range of operating temperature at which testing was performed, bed temperature was found to be the most influential operating parameter. With the exception of coal-fired configuration and excess air at elevated temperatures, bed temperature was the only parameter that had a measurable impact on emissions and efficiency.

Combustion efficiency, a measure of the quantity of carbon that is fully oxidized to  $\text{CO}_2$ , ranged from 96.9–98.9%. Of the four exit sources of incompletely burned

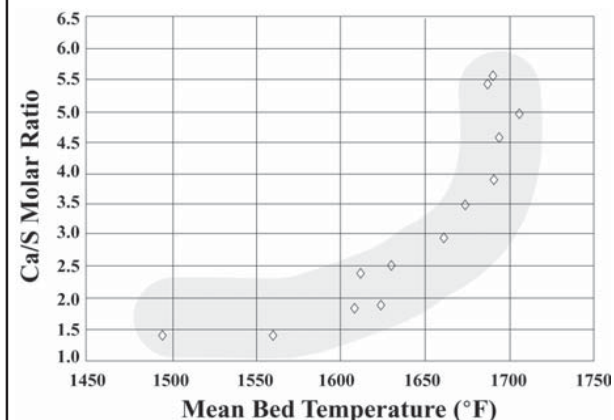


Plant layout with coal and limestone feed locations.

carbon, the largest was carbon contained in the fly ash (93%). The next largest (5%) was carbon contained in the bottom ash stream, and the remaining feed-carbon loss (2%) was incompletely oxidized CO in the flue gas. The fourth possible source, hydrocarbons in the flue gas, was measured and found to be negligible.

Boiler efficiencies for 68 performance tests varied from 85.6–88.6%. The contributions to boiler heat loss were identified as unburned carbon, sensible heat in dry flue gas, fuel and sorbent moisture, latent heat in burning hydrogen, sorbent calcination, radiation and convection, and bottom-ash cooling water. Net plant heat rate decreased with increasing boiler load, from 12,400 Btu/kWh at 50% of full load to 11,600 Btu/kWh at full load. The lowest value achieved during a full-load steady-state test was 10,980 Btu/kWh. These values were affected by the absence of reheat, the presence of the three older 12.5-MWe turbines in the overall steam cycle, the number of unit restarts, and part-load testing.

## Exhibit 3-43 Effect of Bed Temperature on Ca/S Requirement



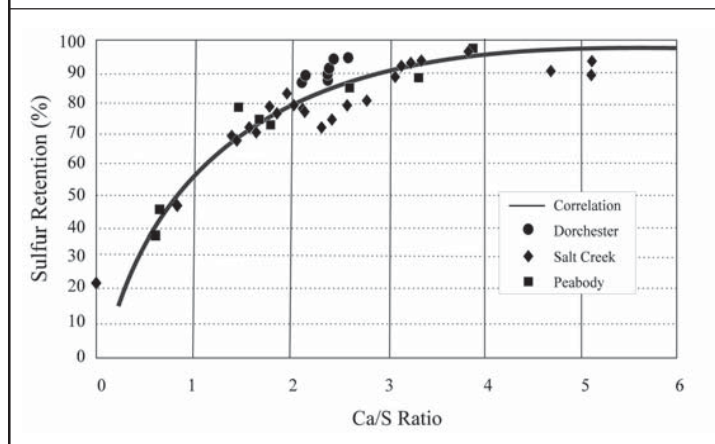
### Environmental Performance

As indicated above, bed temperature had the greatest impact on ACFB performance, including pollutant emissions. Exhibit 3-43 shows the effect of bed temperatures on the Ca/S molar ratio requirement for 70% sulfur retention. The Ca/S molar ratios were calculated based on the calcium content of the sorbent only, and do not account for the calcium content of the coal. While a Ca/S molar ratio of about 1.5 was sufficient to achieve 70% sulfur retention in the 1,500–1,620 °F range, the Ca/S molar ratio requirement jumped to 5.0 or more at 1,700 °F or greater.

Exhibit 3-44 shows the effect of Ca/S molar ratio on sulfur retention at average bed temperatures below 1,620 °F. Salt Creek and Peabody coals contain 0.5% and 0.7% sulfur, respectively. To achieve 70%  $\text{SO}_2$  reduction, or the 0.4 lb/10<sup>6</sup> Btu emission rate required by the licensing agreement, a Ca/S molar ratio of approximately 1.5 is required. To achieve an  $\text{SO}_2$  reduction of 95%, a Ca/S molar ratio of approximately 4.0 is necessary. Dorchester coal, averaging

### Exhibit 3-44

## Calcium Requirements and Sulfur Retentions for Various Fuels



1.5% sulfur content, required a somewhat lower Ca/S molar ratio for a given reduction.

The NO<sub>x</sub> emissions measured throughout the demonstration were less than 0.34 lb/10<sup>6</sup> Btu, which is well below the regulated value of 0.5 lb/10<sup>6</sup> Btu. The average level of NO<sub>x</sub> emissions for all tests was 0.18 lb/10<sup>6</sup> Btu. The NO<sub>x</sub> emissions indicate a relatively strong correlation with temperature, increasing from 40 ppmv (0.06 lb/10<sup>6</sup> Btu) at 1,425 °F to 240 ppmv (0.34 lb/10<sup>6</sup> Btu) at 1,700 °F. Limestone feed rate was also identified as a variable affecting NO<sub>x</sub> emissions, *i.e.*, somewhat higher NO<sub>x</sub> emissions resulted from increasing calcium-to-nitrogen (Ca/N) molar ratios. The mechanism was believed to be oxidation of volatile nitrogen in the form of ammonia (NH<sub>3</sub>) catalyzed by calcium oxide. The CO emissions decreased as temperature increased, from 140 ppmv at 1,425 °F to 70 ppmv at 1,700 °F.

At full load, the hot cyclones removed 99.8% of the particulates. With the addition of baghouses, removal efficiencies achieved on Peabody and Salt Creek coals were 99.905% and 99.959%, respectively. This equated to emission levels of 0.0125 lb/10<sup>6</sup> Btu for Peabody coal and

0.0072 lb/10<sup>6</sup> Btu for Salt Creek coal, well below the required 0.03 lb/10<sup>6</sup> Btu.

### Economic Performance

The final capital costs associated with the engineering, construction, and start-up of the Nucla ACFB system were \$112.3 million. This represents a cost of \$1,123/kW (net). The total power cost associated with plant operations between September 1988 and January 1991 was approximately \$54.7 million, resulting in a normalized cost of power production of 64 mills/kWh. The average monthly operating cost over this period was about \$1,888,000. Fixed costs represent about 62% of the total and include interest (47%), taxes (4.8%), depreciation (6.9%), and insurance (2.7%). Variable costs represent more than 38% of the power production costs and include fuel expenses (26.2%), non-fuel expenses (6.8%), and maintenance expenses (5.5%).

### Commercial Applications

The Nucla project represented the first repowering of a U.S. utility plant with ACFB technology and showed the technology's ability to burn a wide variety of coals cleanly and efficiently. The comprehensive database resulting from the Nucla project enabled the resultant technology to be replicated in numerous commercial plants throughout the world. Nucla continues in commercial service.

Today, every major boiler manufacturer offers an ACFB system in its product line. There are now more than 170 fluidized-bed combustion boilers of varying capacity operating in the U.S. and the technology has made significant market penetration abroad. The fuel flexibility and ease of operation make it a particularly attractive power generation option for the burgeoning power market in developing countries.

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