Ashworth Gasifier-Combustor for Emissions Control From Coal-Fired Power Plants

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The growing role of coal is especially prominent in many emerging economies where rapid urbanization and industrialization are driving the growth in energy demand.[1] In fact, the equivalent of one 500-MW coal-fired power plant has come online every three days since 2010.[2] The president of the World Bank has said that coal will be essential to helping Africa meet its demand for power and alleviate "energy apartheid".[3] Several nations leading the world in economic growth as well as some developed countries are relying heavily on coal-fueled electricity.[4]

As coal-fired power generation around the world increases, the necessity of limiting the emissions becomes increasingly vital. A range of emissions control technologies for all major emissions is currently commercially available. However, especially when power plants are retrofitted, these large pieces of equipment are often piecemealed together, resulting in marginal increases in both the cost of power and the amount of auxiliary power required. In emerging economies these technologies can be cost-prohibitive. Even in the U.S., where inexpensive natural gas has increased competition in the power market, some power plant operators have chosen to shut down coal-fired plants rather than retrofit them with emissions controls. Thus, having options for reducing the costs associated with comprehensive emissions control from coal-fired power plants is globally important to providing affordable, reliable, and low-emissions electricity.

"Three-stage gasification-combustion technology ... can be applied to new or existing power plants."

The Ashworth Gasifier-Combustor, under development by ClearStack Power, LLC, is a low-cost air-blown coal gasification technique that dramatically reduces the major criteria emissions [e.g., NO_x, SO_2, Hg, air metal toxics, and particulate matter (PM)] from a coal-fired power plant when paired with an electrostatic precipitator (ESP). The technology also offers a smaller footprint and draws far less auxiliary power than traditional emissions controls.

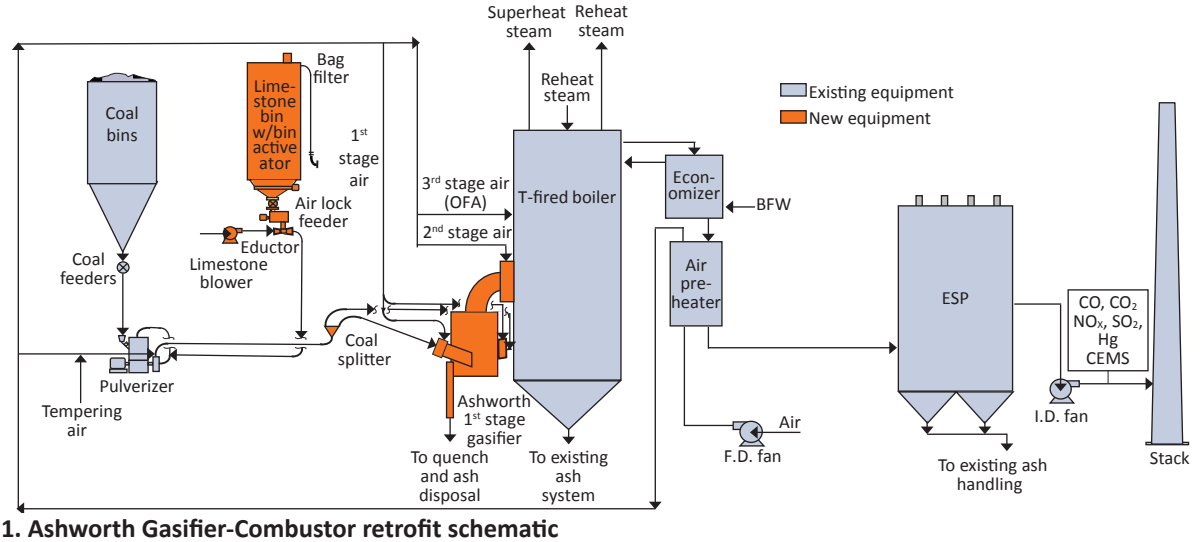

FIGURE 1. Ashworth Gasifier-Combustor retrofit schematic

ClearStack's approach to emissions control is based on a three-stage gasification-combustion technology (see Figure 1), which can be applied to new or existing power plants. In the first stage, pulverized coal is gasified in air in an entrained-flow gasifier to form a mixture primarily of carbon monoxide (CO), hydrogen (H_2), water vapor (H_2O), and nitrogen (N_2, from the injected air). In the first stage limestone is added, which reacts with potential contaminants in the molten ash (i.e., slag) produced. The coal and limestone are fired downward into a molten slag bath, which results in the formation of PM in which the individual particles are larger than what would be created during combustion. When this technology is retrofit to existing power plants the first-stage gasifier takes the place of the burners and is thus fully integrated with the plant. Then, complete combustion occurs in the second and third stages.

The amount of air relative to the coal used in the first-stage gasifier is specifically selected to minimize emissions. For example, an oxygen-deficient environment minimizes NO_x production from the nitrogen in the coal and also provides the optimal conditions to reduce emissions of sulfur (captured through reaction with the limestone), mercury, and other air metal toxics.

More oxygen is available for reaction in the second stage, the lower boiler furnace, to preclude NO_x formation in that stage. Excess oxygen is used for combustion in the third stage of the technology, in the upper boiler, as the gases have cooled to a point that minimizes thermal NO_x production. Using less excess air throughout the gasification and combustion processes also increases the overall plant efficiency.

"Gasifying prior to combustion produces nonhazardous, salable inert slag and fly ash."

TECHNOLOGY BENEFITS

Reducing Criteria Emissions

The principal objective of the Ashworth Gasifier-Combustor technology is to reduce emissions from coal-fired power plants in a cost-effective manner. Environmental benefits are listed in Table 1.

The approach of gasifying prior to combustion produces nonhazardous, salable inert slag and fly ash. Since selective catalytic reduction is not required (because NO_x formation is avoided during combustion), chemicals like ammonia are not required. Similarly, since no water is sprayed into the flue gas as is the case with wet desulfurization scrubbers, no visible water vapor is observed at the power plant stack.

In addition to comprehensively reducing emissions, the technology also offers several co-benefits. Approximately 75% of the fly ash, or PM, is captured and removed with the molten slag produced in the gasifier. Because the PM generated is larger than what is created during combustion, the PM that is not removed with the slag is less harmful and also is more efficiently captured by an ESP, since larger particles are easier to capture. Thus, a

TABLE 1. Environmental benefits

Emission or benefit	*Emission level*	*Reduction in emissions compared to baseline, %*	*Notes*
NO_x	≤0.095 lb/10^6 Btu	~80%	Three-stage oxidation effect
SO_2	Depends on coal used	~95–100%	Ca/S ratio = 1 with fine limestone
CO	7–8 ppmvd (parts per million volumetric, dry)	~95%	@3% O_2 (Alstom modeling for T-Fired boiler)
Hg	Depends on coal used	~90–100%	Captured in slag/fly ash; leachate tests of slag and fly ash demonstrate 0 mg Hg/L in the leachate
Sb, As, Ba, Be, Cd, Cr, Co, Cu, Pb, Mo, Ni, Se, Ag, Tl, V, Zn, and Mn	Depends on coal used	~100% (except 80% Mn)	Captured in slag and fly ash; leachate tests showed concentrations of Ag, As, Ba, Cd, Pb, and Se in the leachate were all below the U.S. EPA regulatory limit for both the slag and fly ash. Thus, slag and fly ash are nonhazardous to human health.

combined gasification-combustion approach would reduce plant emissions using the same ESP (in the case of a retrofit). For example, with a particular ESP using a voltage of 94 kV,[5] employing the gasifier-combustion operation would yield an overall PM removal of 99.32 wt% compared to removal from flue gas from a conventional coal-fired unit of 94.96 wt% (see Table 2).

Another benefit is that the ash is more alkaline because limestone is mixed with the coal. Research has shown that the alkali and alkaline earth metal concentrations are important factors in reducing the resistivity of the fly ash (to improve the ease of capture).[6]

Carbon Emissions

In addition to criteria emissions, the technology can reduce carbon dioxide (CO_2) emissions. First, it can be applied to biomass/coal mixtures, thus reducing carbon emissions. Up to 15% of the coal could be replaced with biomass. While conventional boilers can cofire some 10% biomass, the reactive alkalis, such as sodium and potassium, can decrease boiler tube life. In the gasification-combustion system under development, these compounds are mostly tied up with other minerals in the slag and thus not as much of a concern.

In addition, the required auxiliary power is far less than traditional emissions control options. When using the traditional emissions controls combination of low-NO_x burners, selective catalytic reduction, and a wet FGD system, a 580-MW power plant might have 15 MW of parasitic energy consumption (meaning that the plant can only sell 565 MW), not including the ESP and other auxiliary power draws required by both systems. However, the only parasitic energy used by the Ashworth Gasifier-Combustor process is that for treatment and injection of the limestone. Thus, the parasitic energy for a similarly sized plant would be 0.5 MW instead of 15 MW and a 580-MW power plant could sell 579.5 MW of electricity. In addition, certain coals with high-calcium ash, such as some Powder River Basin coals, would not require limestone addition. In that case the auxiliary power for emissions controls could be negligible. With each improvement in efficiency the CO_2 emissions are decreased.

TABLE 2. ESP PM removal performance

Particle size	*<PM_5, %*	*PM_5–PM_{10}, %*	*>PM_{10}, %*	*Overall efficiency, %*
Gasifier-combustion fly ash	0.50	2	97.5	**99.32**
Conventional coal burner fly ash	13	12	75.0	**94.96**
ESP efficiency	65	99	99.5	

In the long term, if the technology is applied to new ultra-supercritical boilers that currently achieve 45–46% overall thermal efficiency,[7] a power plant built with the Ashworth Gasifier-Combustor would be more efficient than a coal-based integrated gasifier combined-cycle (IGCC) power plant. It would also require less space and would be less expensive to install and operate.

Saleable By-Products

Since the advent of low-NO_x burners and activated carbon injection for mercury capture, many coal-fired power plants that once sold their fly ash to the cement industry are no longer able to do so due to increased carbon content. As the Ashworth Gasifier-Combustor results in fly ash with 5 wt% carbon or less, it is suitable for sale to the construction industry. The slag from the first-stage gasifier could also be saleable since coal-fired cyclone boiler slag is currently used as a wear-resistant component in surface coatings of asphalt for road paving. Finer-sized slag could also be used as blasting grit and is commonly used for coating roofing shingles.

PRELIMINARY ECONOMICS

Preliminary economics have been calculated for the Ashworth Gasifier-Combustor. For a retrofit, the costs are compared with a FGD scrubber to remove SO_2 and Hg plus selective catalytic reduction (SCR) for NO_x control (see Table 3). The comparison

TABLE 3. 200 MW_e cost comparison (2015US$)

Technology	*Capital Cost, US$*	*$/$kW_e$*	*Incremental operating cost, $/yr*	*¢/kWh*
Ashworth Gasifier-Combustor	$29,000,000	$145	$6,500,000	0.46
Selective catalytic reduction	$36,700,000	$183.50	$7,800,000	0.56
Wet desulfurization scrubber	$38,900,000	$194.50	$10,200,000	0.73
Total	$75,600,000	$378.00	$18,000,000	1.29

assumes the same environmental performance for the two emissions control options. A 200-MW_e T-fired coal boiler firing run of mine bituminous coal was used as the basis for the retrofits. For calculation of operating costs, an 80% capacity factor was used.[A] The capital and operating costs are based on 2015 U.S. dollars.

The Ashworth Gasifier-Combustor was calculated to be ~38% of the capital cost and 36% of the operating cost compared to the conventional emissions control technologies. Also, this analysis does not include any credit for other air metal toxics (80–100%) that are removed by the gasifier and/or greater ESP performance. In addition, because the ash and slag are saleable, the economics could actually improve further.

DEMONSTRATING THE TECHNOLOGY

The Ashworth Gasifier-Combustor was demonstrated at a 4-MW_e scale at the Lincoln Developmental Center, in Lincoln, IL, U.S., on a coal-fired stoker (see Figure 2).[8] The gasifier was incorporated into boiler operation. The gasifier design modifications were successful in increasing sulfur capture and reducing NO_x emissions compared to the original two-stage Florida Power Corporation "CAIRE" gasifier-combustor to which ClearStack owns the rights and completed testing at the Foster Wheeler Development Center.[9]

LOOKING FORWARD

Today this gasification-combustion technology remains under development. Currently, ClearStack is seeking a project partner in the U.S. to demonstrate the technology on an existing 20–75-MW_e coal-fired power plant. The objective of the collaboration would be to retrofit the technology in order to meet the U.S. EPA Mercury and Air Toxics Standards. Depending on the environmental permit requirements, it will take 18 to 24 months to retrofit the technology onto an existing coal-fired plant in the U.S. Pending a successful demonstration, ClearStack will look to deploy the technology at power plants needing emissions control both in the U.S. and abroad.

FIGURE 2. Ashworth Gasifier-Combustion system (40 million Btu/hr)

NOTES

A. The Ashworth Gasifier-Combustor is applicable to coal-fired power plants of any size. A 200-MW_e plant was chosen for the economic analysis because this represents the most likely near-term customers in the U.S.

REFERENCES

1. Advanced Energy for Life. (2015). The world is counting on coal to power growing needs, www.advancedenergyforlife.com/article/world-counting-coal-power-growing-needs (accessed April 2015)
2. BP. (2014). Energy outlook 2035, www.bp.com/en/global/corporate/about-bp/energy-economics/energy-outlook.html
3. Kim, J.Y. (2014, 1 April). Speech by World Bank Group President Jim Yong Kim at the Council on Foreign Relations, www.worldbank.org/en/news/speech/2014/04/01/speech-world-bank-group-president-jim-yong-kim-council-on-foreign-relations
4. Watanabe, C. (2015, 9 April). Japan's new coal plants threaten emission cuts, group says. Bloomberg Business, www.bloomberg.com/news/articles/2015-04-09/japan-s-new-coal-plants-threaten-emission-cuts-group-says
5. Haque, S., & Rasul, M.G. (2009). Thermal power plant: Performance improvement of electrostatic precipitator, www.knovelblogs.com/2009/12/03/ecthermal-power-plant-performance-improvement-of-electrostatic-precipitator/
6. Wheland, B., Devire, G., Pohl, J.H., & Creelman, R.A. (2000). The effect of blending coals on electrostatic precipitator performance American Chemistry Society, Energy & Fuels (preprint), web.anl.gov/PCS/acsfuel/preprint%20archive/Files/45_1_SAN%20FRANCISCO_03-00_0024.pdf
7. Power-Technology.org. (2007). Yuhuan 1,000MW ultra-supercritical pressure boilers, www.power-technology.com/projects/yuhuancoal/
8. Ashworth Combustor Demonstration Final Report. (2003, 15 May). ClearStack Combustion Corporation for the Illinois Department of Commerce and Community Affairs and the Illinois Clean Coal Review Board.
9. Ashworth, R.A., & Padilla, A.A. (1992). "CAIRE" Advanced Combustor Development. Presented at the Ninth Annual International Pittsburgh Coal Conference, Pittsburgh, PA, www.clearstack.com/wp-content/uploads/CAIRE-Advanced-Combustor-Development.pdf

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