Strategies for Improving Efficiencies in Oxy-Combustion Retrofits

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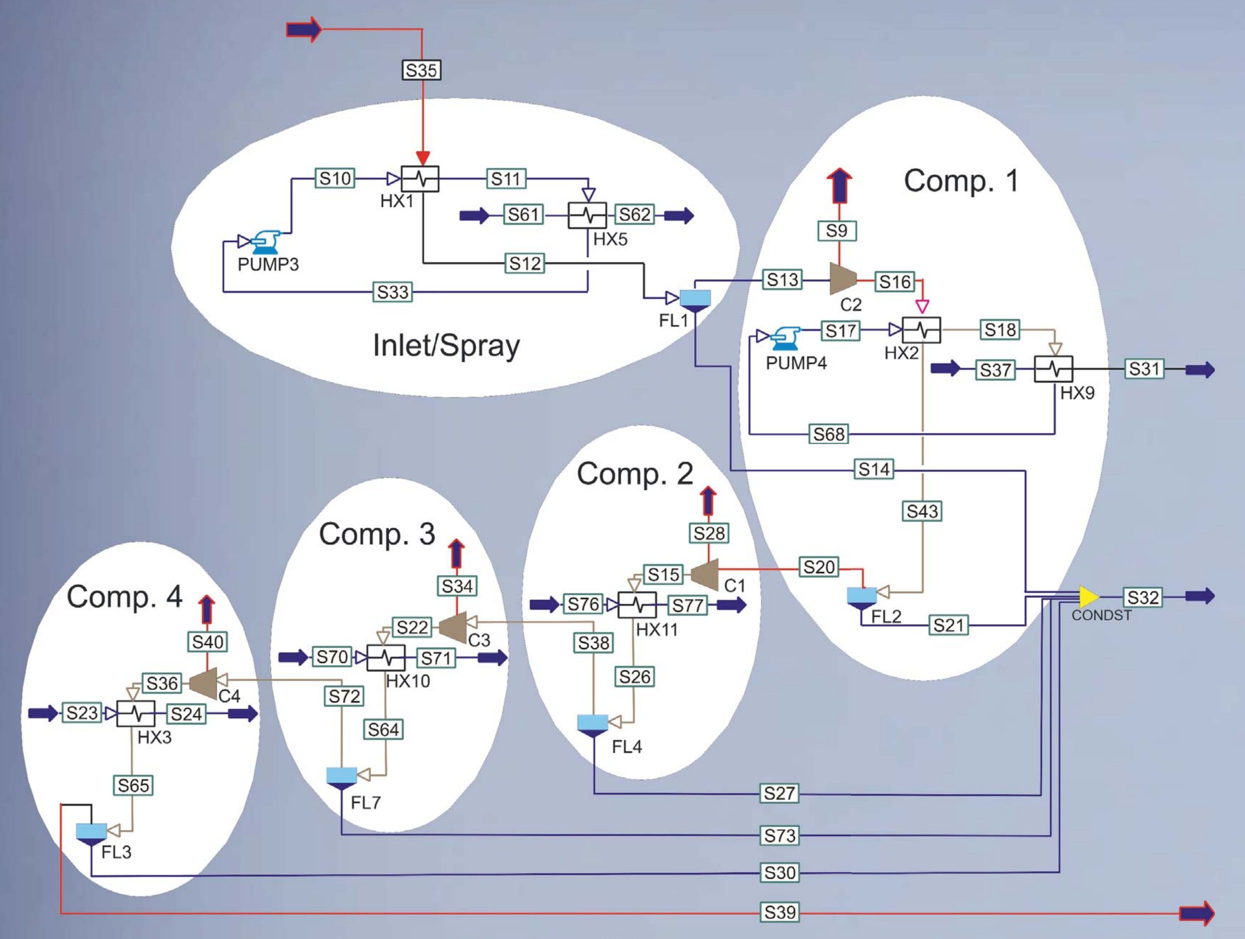
Abstract

Oxy-fuel combustion is a promising approach to both new generation and retrofit fossil-fuel power plants. This approach uses oxygen independent of air as the oxidizer, resulting in a CO_2-rich flue gas stream suitable for sequestration. Impacts that must be addressed include efficiency losses, changes in flame characteristics, and materials performance. NETL is conducting lab and field studies in oxy-fuel systems to identify opportunities to conserve and recover useful energy, evaluate radiative and flame properties, and characterize corrosion of construction materials. One strategy for improving efficiency integrates CO_2 capture with the power plant thermal cycle. NETL uses GateCycle©, a commercially available software, to characterize retrofit pc oxy-combustion plants with Integrated Pollutant Removal (IPR™). Comparisons of various configurations identify promising approaches to efficiency gains.

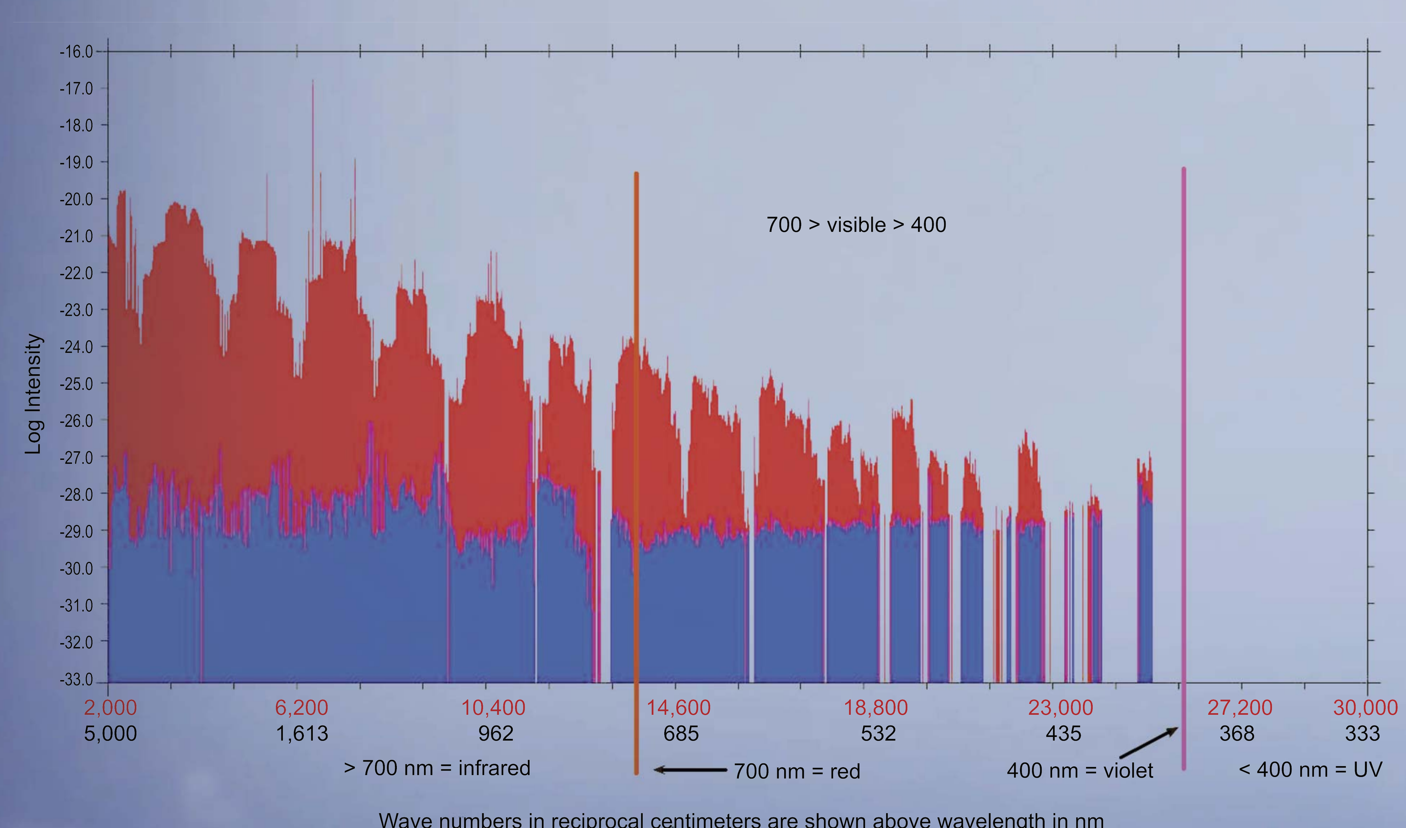


The Integrated Pollutant Removal (IPR™) Process

The NETL-developed IPR™ process treats and captures the off-gas from an oxy-combustion steam boiler. This cartoon, adapted from GateCycle© thermal cycle modeling software for power plants, shows the process and flows implemented in an IPR system.

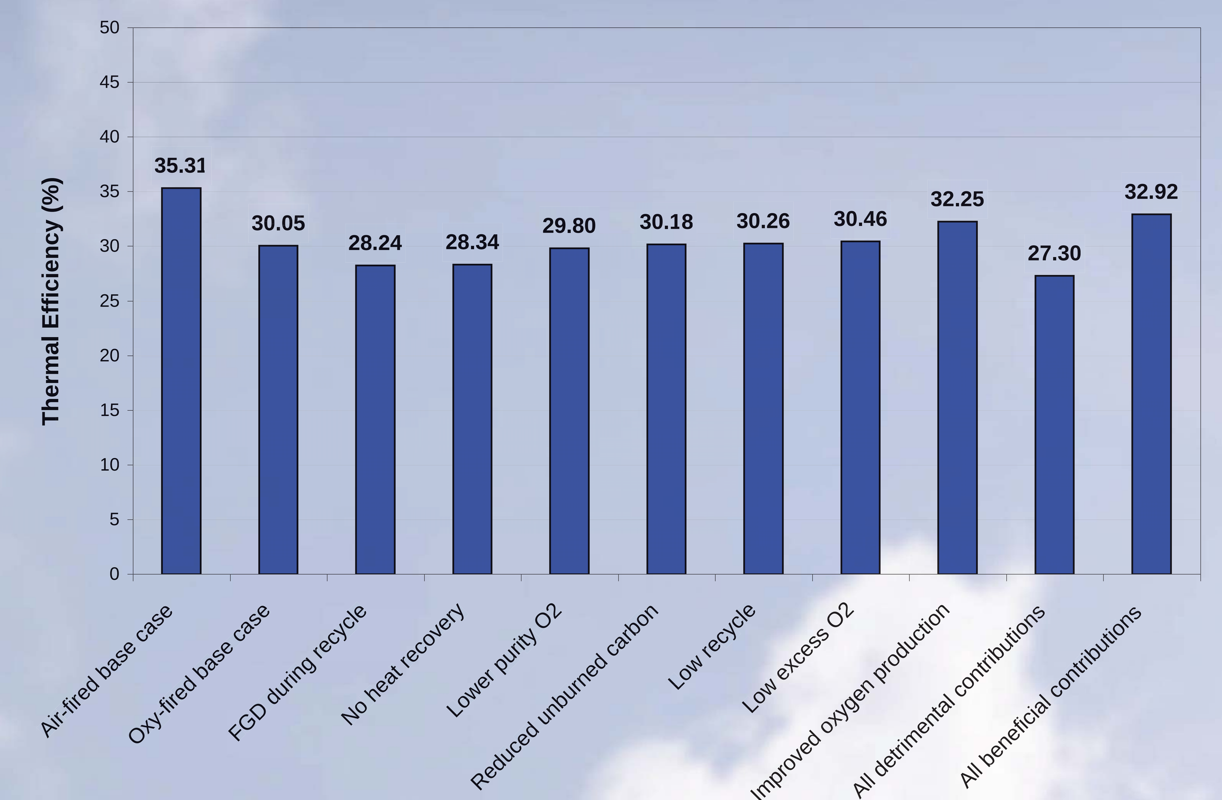
In the Inlet/Spray section, the input (S35) is combustion gas from an oxy-combustion boiler after removal of coarse particles. This gas, dominantly water and CO_2, is cooled in a heat exchanger (HX1) with condensation of water and, if reagents are added, acid gases. The cooling fluid in this heat exchanger is cooled, recirculated, and reused. The gas and condensed water are separated in a flash tank (FL1), with the gas (S13) proceeding to compression, cooling, and further condensation; and the liquid (S14) to a combined condensate stream.

Comp. 1 begins compressing the gas at C2, further cools it at HX2 with a cooled recirculating fluid, recovering heat added during compression, and separates additional condensate at FL2. The three remaining compression steps are similar to one another and continue to compress (C1, C3, C4), cool (HX11, HX10, HX3), and condense (FL4, FL7, FL3) the fluid. The final products are CO_2 gas at > 90% purity (S39), condensate (S30, S73, S32), and cooling fluids (S62, S31, S77, S71, S24), which carry recovered energy that is re-incorporated into the power plant's thermal cycle.



CO_2 and H_2O Spectrum - Intensity Shown as Log Value

Carbon dioxide and water vapor spectra illustrating the strong emissions and absorption in the infrared range for oxy-fuel combustion products. Lower concentrations of CO_2 and H_2O in the combustion products of standard air-fired boilers result in less importance of IR radiation in the transport of heat throughout the boiler. Heat transfer in oxy-combustion systems is presently not fully understood because of the strong influence of water vapor and carbon dioxide in the boiler.



Improving Oxy-Combustion Power Plant Efficiency

Transition from air-fired pc combustion to oxy-combustion requires careful examination of each required and potential change. NETL GateCycle© modeling evaluated a number of factors for their impact on thermal efficiency in a sub-critical single reheat pc power plant.

- Lower-energy oxygen production
  - i.e., advanced technologies entering the market
- Reduction of excess O_2 in oxy-fuel exhaust products
- Reduced flue gas recirculation to the boiler
  - increases O_2 concentration in the comburent from 38% to 61% O_2
  - requires heat transfer surface modifications in a retrofit system
- Improved carbon burnout
  - reduction in unburned carbon from 1.0% to 0.5%
- Reduction in oxygen purity
  - from 99% to 95.5%
- Lack of heat recovery during carbon capture
- Flue gas desulfurization (FGD) during recycle

The modeling showed that the greatest improvements in heat rates could be achieved through lower-energy oxygen production, elimination of FGD during recycle, and recovering useful heat during exhaust gas processing.

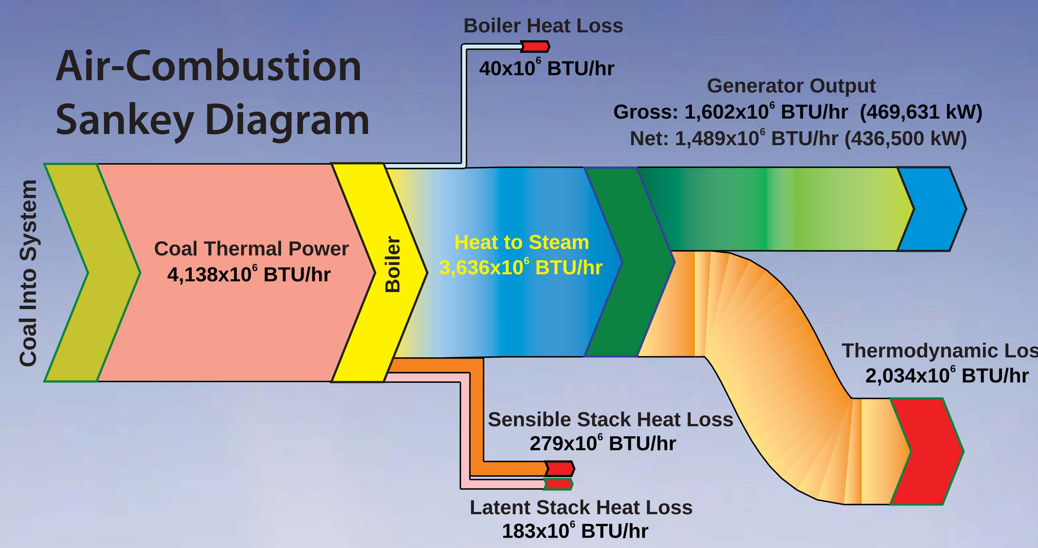
Field Demonstration of Oxy-Combustion Burner Test and IPR™

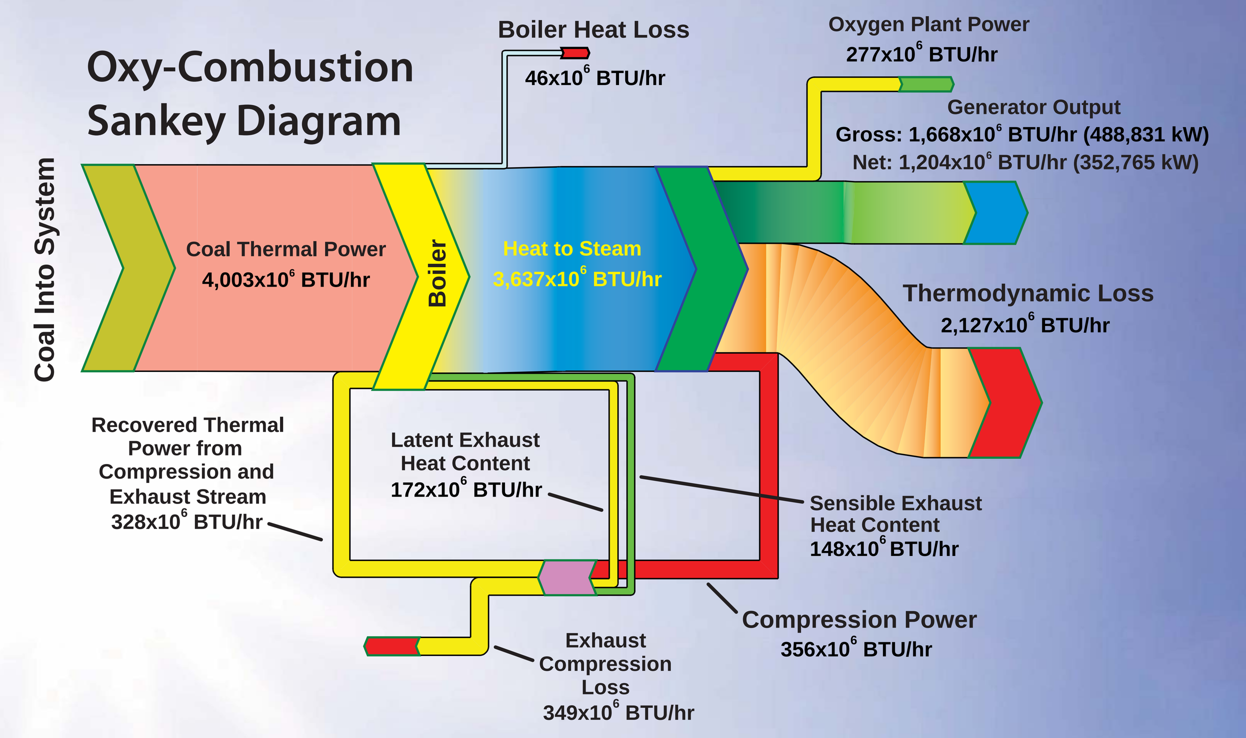
A cooperative research effort between NETL and the Jupiter Oxygen Corporation (JOC) is focused on development of pulverized coal oxy-combustion and carbon capture via IPR™ for future commercialization. JOC has modified a package B&W boiler in a 5 MW (thermal) test facility to evaluate flue gas recycle rates and other aspects of oxy-combustion. An IPR™ system is being constructed and shaken down to investigate heat recovery rates as a means to optimize efficiency in oxy-combustion carbon capture systems. Data from the operation of this combined system will also be used to develop and validate systems analyses and CFD modeling codes for oxy-fuel combustion systems.

This under-construction facility:

- Boiler (right background), oriented with the burner at the right end;
- Stack and cyclone in front of the boiler;
- Control and data collection room at left in the background;
- Flue gas recirculation system;

IPR™ system will be sited in the left foreground to process a portion of the recirculated flue gas.



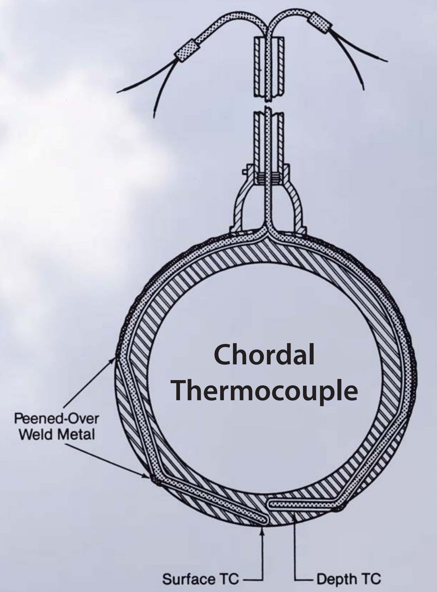


Comparison of Energy Flows in Air Combustion and Oxy-Fuel Combustion

These Sankey diagrams show energy flows in the modeled baseline air-fired and oxy-combustion systems . The two cases have similar heat-to-steam outputs, but other elements of the diagrams demonstrate the differences between the two types of systems.

- Most obvious is the partial energy recovery step shown in the loop at the bottom of the oxy-combustion diagram (bottom), which represents exhaust energy (latent heat, sensible heat, and energy from compression of CO_2 to pipeline pressure)
- The oxy-combustion system requires an oxygen plant (power requirement shown at the top right of the oxy-combustion diagram), which reduces the generator output
- Comparison of inputs shows about 3% less coal required by the oxy-combustion system to produce the same amount of steam
- The amount of latent heat in both cases is very similar (within 11×10^6 BTU/hr), because latent heat content in water vapor is directly related to the amount of coal burned (which is similar in the two systems)

Sensible heat exiting the oxy-combustion boiler is reduced by about 47%, due to the fact that there is no nitrogen to carry out additional sensible heat. Nitrogen in air-based combustion systems is an inert carrier of energy instead of an active participant in combustion (as are carbon dioxide and water vapor in oxy-combustion).



Heat Transfer Through Boiler Tube Walls

Chordal thermocouples are being used at the Jupiter Oxygen Corporation oxy-combustion burner test facility for measurement of temperature gradients in boiler tube walls. The chord-drilled holes through which the thermocouples approach the inner and outer surfaces of the tube are very small, in order to minimize the effect on heat flow. The temperature measurements that are made will characterize the heat flux in a package boiler which has been converted to oxy-combustion (Steam 41).

References

Steam: Its Generation and Use, Edition 41. The Babcock & Wilcox Company, 2005.

Ochs, Tom, Oryshchyn, Danylo, Summers, Cathy, Gerdemann, Steve. Oxy-fuel Combustion and Integrated Pollutant Removal as Retrofit Technologies for Removing CO_2 from Coal Fired Power Plants. Proceedings of PowerGen International, 2007.