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Oxy-combustion Carbon Capture for Pulverized Coal in the Integrated Environmental Control Model

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Abstract

This paper describes the newly-developed techno-economic models of oxy-combustion carbon capture systems for pulverized coal-fired power plants now available in the Integrated Environmental Control Model (IECM) developed and maintained by Carnegie Mellon University. The new model is used in case studies that compare the overall performance and cost of electricity generation for power plants employing either oxy-combustion (oxyfuel) or an amine-based post-combustion process to capture and sequester 90% of the flue gas CO_2 emission using a variety of U.S. coals. The probabilistic results for 500 MW plants using three coal types (bituminous, sub-bituminous and lignite) show that the oxyfuel option is cost-competitive or less costly than the post-combustion option, especially for the lower-rank low-sulfur coals. However, oxy-combustion would not be cost-competitive as a compliance option for the recently promulgated New Source Performance Standard (NSPS) for CO_2 in the United States, which requires CO_2 capture levels well below the capability of current technology. Other case studies show that alternative policy options, such as a tax on CO_2 emissions, could incentivize oxy-combustion capture.

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Keywords: Oxy-combustion; carbon capture and storage; power plant performance and cost; environmental policy.

1. Introduction

Among the three major technological approaches to carbon capture and storage (CCS) at coal-fired power plants (involving pre-combustion, post-combustion, and oxy-combustion capture systems), there remains a disparity in the current level of development of each option. Government-supported projects for pre-combustion capture, such as at

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Kemper County, as well as post-combustion capture, such as at Boundary Dam and Petra Nova, have helped advance those technologies to commercial-scale demonstrations. However, proposed large-scale oxy-combustion projects, such as FutureGen 2.0 and other non-U.S. projects, have not yet achieved that level of development [1].

Despite a number of setbacks, however, significant progress still has been made over the past decade in the design and optimization of oxy-combustion systems for coal-fired power plants. This paper draws upon current information to develop a computer-based model of the performance and cost of oxy-combustion carbon capture systems for pulverized coal (PC) electricity generating units. In particular, recent studies by the U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) [2] the Electric Power Research Institute (EPRI) [3], and the International Energy Agency Greenhouse Gas Programme (IEAGHG) [4] provide a baseline for the current state of the technology.

The generalized model developed in this work is used to extend the technology evaluations and assessments currently available in the literature. In particular, we characterize the performance and cost of alternative oxy-combustion configurations over a broad range of parameters, and further quantify the uncertainty and variability in these results using probabilistic methods. We further apply these methods to assess the viability of oxy-combustion technology relative to competing post-combustion CCS systems for coal-fired power plants if a market for CCS were to materialize. The current regulatory environment also is discussed in the context of EPA's recently promulgated New Source Performance Standards (NSPS) for power plant CO_2 and the design parameters and regulatory constraints that would best incent the development of oxy-combustion systems.

2. Techno-economic model overview

In order to evaluate PC oxy-combustion systems across a range of design parameters, a techno-economic model of this carbon capture technology was developed using information from several recent studies [2, 4-5]. Here, we present brief overviews of the two major elements of the model: the oxy-combustion performance model and the process cost model. Full details of both models, including all individual process components, can be found elsewhere [6].

The oxy-combustion performance model relies on the integration of several process component models to achieve an overall mass and energy balance. Each of the process components is comprised of mass and energy balance equations and performance input parameters unique to the function of that equipment. Process flow information for the air separation unit, carbon processing unit, direct contact cooler, particulate handling and sulfur treatment systems is handled iteratively for a given fuel flow rate, until a steady-state solution for the overall plant is achieved. The plant configuration (size and location of recycle streams) and required sulfur removal equipment is determined based on the moisture and sulfur content of the fuel.

The two process flow diagrams of Figure 1 are representative of the two major plant configurations of the oxy-combustion model. The location and size of the secondary flue gas recycle (FGR) stream are major determinants in the thermal efficiency and economics of the overall plant. Acceptable concentration limits for moisture and sulfur oxides in the recirculated flue gas constrain the extent to which secondary recycle may be employed. The "warm recycle" process (right) allows the secondary recycle stream to be split off prior to sulfur treatment. The advantage of this configuration is that it allows a high thermal energy recycle stream to be returned to the boiler, which consequently enables higher plant efficiency. This configuration, however, is viable only for plants using low-sulfur coal. For high-sulfur coals, a "cold recycle" design is needed to satisfy a hierarchy of constraints which govern the mass flow rate of the recycle and flue gas streams. Table 1 illustrates these constraints for the model that has been developed. This set of mass flow constraints ensures that feasible model plant configurations are realized in a computationally efficient manner.