Systems Analysis of Advanced Power Plant Carbon Capture Technologies

Investigators
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Abstract
This project will develop a flexible but powerful systems analysis modeling capability that relates the multiple design and performance parameters of different electric power generation systems to the process parameters and material properties that influence the overall performance and cost of carbon capture technologies applied to reduce emissions of carbon dioxide (CO_2) to the atmosphere. The systems model will employ and substantially expand the Integrated Environmental Control Model (IECM) framework developed in prior research by Carnegie Mellon University. This model, rooted in fundamental mass and energy balance principles, can be used to conduct comparative analyses of emergent capture technology options for different types of power plants, including rigorous treatment and analysis of uncertainties, which are especially prevalent in emerging technologies. We will employ the new IECM models for advanced carbon capture options to determine the primary technical targets necessary to meet the cost goals for power plants with carbon capture and storage. The expanded IECM will be used to help identify the most promising new options and R&D goals for advanced capture technologies and examine environmental impacts of carbon capture on a life cycle basis.

Introduction
To mitigate global climate change, carbon capture and storage (CCS) is a key technology option for achieving large reductions in CO_2 emissions from the use of fossil fuels or biomass as an energy source [1]. Today's commercially available CCS technology is an amine-based capture system in which CO_2 is separated from flue gases and then compressed to a liquid-like state for transport to a suitable storage site [2]. However, adding amine-based CCS to pulverized coal (PC) power plants for 90% CO_2 capture would increase the plant-level cost of generating electricity by roughly 70% to 80% while incurring an energy penalty of about 25% to 40% more fuel input per unit of electricity shipped to consumers [3-4]. Thus, there is a strong research focus on developing advanced capture processes having lower energy requirements and lower overall cost than current systems.

Given the wide range of activities and approaches to advanced carbon capture, there is a strong need for a systems analysis capability to provide "a common ground" to evaluate emergent carbon capture technologies. This project will develop such a capability in accord with the characteristics sought by the Global Climate and Energy Project (GCEP):

- An excellent scientific basis rooted in the fundamentals;

- A model that relates the performance parameters with process parameters and material properties;
- The potential to allow comparative analyses of emergent capture technology options;
- Case studies of technologies supported by other GCEP funding;
- A methodology to assist GCEP in identifying the potential for a "breakthrough" in a full-scale power generation system.

Background

There are many ways to define a "system." The main focus here is on the capture process in the context of a complete fossil fuel power plant. The evaluation of a CO_2 capture technology—in particular, its impact on overall plant emissions, performance and cost—depends not only on the design and operation of the capture unit itself, but strongly on the design and operation of the power plant to which the capture unit is attached. Thus, factors such as the base power plant efficiency, plant fuel properties, pollution control equipment design, and degree of plant utilization also weigh heavily in any quantification of the impacts of a CO_2 capture technology. Consequently, any systems model intended to help guide research priorities and identify potential "breakthrough" technologies must include not only the CCS system, but also a reasonable set of the different power generation options where CCS might be employed. Analytical models should include both performance models (based on fundamentals and relevant empirical data) as well as economic costing models. Uncertainty analysis and quantification should play a prominent role in technology assessments and evaluation.

Our research team will draw on a rich history of systems analysis reserach focused on technologies to reduce power plant emissions. A product of that research is a systems analysis model called the Integrated Environmental Control Model (IECM), depicted schematically in Figure 1 [5]. The IECM provides estimates of the performance, resource requirements, emissions and cost of a variety of conventional and advanced fossil fuel power plants including pulverized coal (PC), integrated gasification combined cycle IGCC), and natural gas combined cycle (NGCC) systems. The IECM framework includes process performance models, engineering economic models, and probabilistic analysis capability. The IECM's graphical interface allows a user to specify a plant configuration of interest, set values for key parameters, and get results in tabular or graphical form.

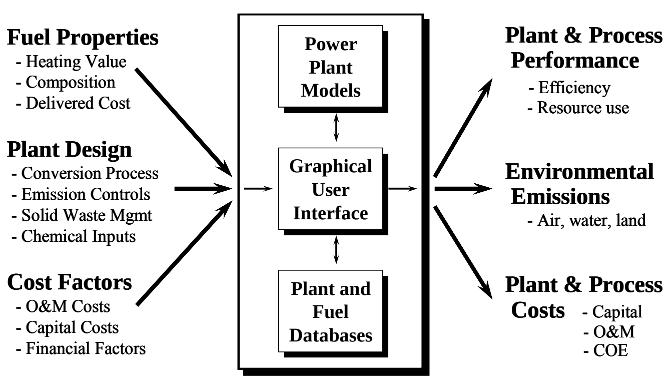

Figure 1. Schematic of the IECM software package showing major inputs and outputs

A core element of this project is the development of models to characterize several emerging CO_2 capture processes being developed with GCEP funds. These involve the use of materials such as ionic liquids, metal organic frameworks (MOFs), and biomimetic sorbents. In this project we propose to substantially expand the IECM framework to explicitly include models of these advanced CO_2 capture processes, plus the capability to include a life cycle analysis (LCA) of substances used for CO_2 capture. This system-level model will then be employed to quantify key performance metrics, and to conduct case studies and comparative analyses of emergent capture technology options in both deterministic and probabilistic forms [6].

Results
This project was initiated just several weeks ago on February 19, 2013. Thus, there are no results to report at this time.

Progress
We initialized work on the first task outlined in our proposal, namely, reviewing the literature on such new materials as ionic liquids and MOFs used for CO_2 capture, and assessing the status of available data on process and material properties needed for thermodynamic modeling. In addition, we have initiated contact with other GCEP researchers to develop the collaborative relationships sought in this research. The first such development has been with the GCEP-funded research group at the University of Notre Dame headed by Prof. Joan Brenneke. Her group is developing ionic liquids for use in pre-combustion CO_2 applications.

Future Plans
The set of planned tasks for fulfilling the goals of this project include the following:

- Task 1: Review literature and material properties data.
- Task 2: Formulate capture process designs.
- Task 3: Formulate thermodynamic process models.
- Task 4: Develop reduced-order performance models (as needed).
- Task 5: Formulate technology-level cost models.
- Task 6: Conduct initial techno-economic assessments.
- Task 7: Embed capture technology in alternative plant-level models.
- Task 8: Characterize uncertainty/variability of key process parameters.
- Task 9: Develop LCA capability for CO_2 capture system and materials.
- Task 10: Assess plant-level attributes and targets.
- Task 11: Conduct comparative case studies.
- Task 12: Document and disseminate project results.

Publications
None at this stage.

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