A Technical and Economic Assessment of Advanced Carbon Capture Technologies

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Abstract

The U.S. Department of Energy’s National Energy Technology Laboratory (DOE/NETL) has proposed cost targets for new generation technologies for carbon dioxide (CO$_2$) capture: $40$/tonne CO$_2$ captured by 2020 and $30$/tonne CO$_2$ captured by 2030, not including transport and storage costs. To reach these targets, a large amount of research and development (R&D) has been conducted on three major categories of materials for CO$_2$ capture: sorbents (e.g. metal organic frameworks, zeolites, metal oxides-based adsorbents), solvents (e.g. aqueous piperazine, ionic liquids, chilled ammonia), membranes (e.g. facilitated transport membranes, mixed matrix membranes). The major objectives of this study are to review state-of-the-art technologies using novel sorbents, solvents, and membranes for CO$_2$ capture; comparatively examine their recent material properties, process engineering, and engineering-economics with special attention to post-combustion CO$_2$ capture applications; and further identify urgent R&D needs for advanced capture technologies in meeting the NETL’s cost targets. Specific research missions for each category are illustrated as follows:

- **Material Properties.** For sorbents and solvents, the major properties of interest will include adsorption or absorption capability, specific heat capacity, heat of adsorption or absorption, and viscosity, while the major properties of interest for membranes will include permeability and selectivity. For each category, this study will compare major properties among various materials and examine the variability in material properties by pressure and temperature, as well as the effects of water vapor and minor air pollutants on CO$_2$ adsorption or absorption capacity or CO$_2$ permeability.

- **Process Engineering.** This study will identify most feasible process configurations and typical designs of operating pressure and temperature. The major process performance parameters of interest will include the thermal and electric power requirements and overall
energy penalty for CO₂ capture, cooling duty, and material degradation. This study will also examine the variability in major performance parameters by CO₂ separation targets on recovery rate and product purity.

- **Engineering-Economics.** This study will compare the overall costs of CO₂ captured and avoided plus the added cost of electricity generation for CO₂ capture for post-combustion applications. This study will also examine the variability in major cost metrics by CO₂ separation targets.

Three sets of data will be collected and assembled based on peer-reviewed publications and patent databases. For each category, this study will highlight advantages, disadvantages, challenges, and potential solutions to improve the viability. Advanced capture process options in the three categories will be compared in terms of the overall energy penalty and the cost of CO₂ captured or avoided to identify “step-out” capture technologies, including innovative hybrid designs that can integrate multiple materials or technologies into a single system and then utilize their individual strengths to lower energy and cost penalties.

Based on the review results, this study will further determine the material property targets and process performance requirements for the most promising technologies in meeting the NETL’s cost targets for CO₂ capture. To achieve this objective, an empirical model that relates major material properties, process performance parameters and cost factors to the overall capture cost will be developed for the selected capture technologies based on the assembled data. The Integrated Environmental Control Model (IECM), a power plant modeling tool developed by Carnegie Mellon University, has been enhanced significantly by incorporating a variety of CO₂ capture technologies into the common framework, such as membranes, ionic liquids, and solid sorbents. Both the empirical model and IECM will be employed jointly for a “reverse-engineering” to identify “ideal” materials properties, process performance and material prices necessary to achieve the capture cost targets. The results of this analysis can guide the direction of R&D programs for advancing CO₂ capture technologies.