A Technical, Economic, and Environmental Assessment of Amine-Based CO₂ Capture Technology for Power Plant Greenhouse Gas Control

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Capture and sequestration of CO₂ from fossil fuel power plants is gaining widespread interest as a potential method of controlling greenhouse gas emissions. Performance and cost models of an amine (MEA)-based CO₂ absorption system for postcombustion flue gas applications have been developed and integrated with an existing power plant modeling framework that includes multipollutant control technologies for other regulated emissions. The integrated model has been applied to study the feasibility and cost of carbon capture and sequestration at both new and existing coal-burning power plants. The cost of carbon avoidance was shown to depend strongly on assumptions about the reference plant design, details of the CO₂ capture system design, interactions with other pollution control systems, and method of CO₂ storage. The CO₂ avoidance cost for retrofit systems was found to be generally higher than for new plants, mainly because of the higher energy penalty resulting from less efficient heat integration as well as site-specific difficulties typically encountered in retrofit applications. For all cases, a small reduction in CO₂ capture cost was afforded by the SO₂ emission trading credits generated by amine-based capture systems. Efforts are underway to model a broader suite of carbon capture and sequestration technologies for more comprehensive assessments in the context of multipollutant environmental management.

Introduction

The control of greenhouse gases is arguably the most challenging environmental policy issue facing the U.S. and other countries. An approach that is gaining widespread interest is to control CO₂ emissions by capturing and sequestering CO₂ from fossil-fuel combustion sources (1, 2). The key attraction of this option is that it can allow fossil fuels to continue to be used without contributing significantly to greenhouse warming. This would be a radical departure from conventional thinking about climate mitigation, which would require eliminating or severely limiting the use of fossil fuels. Given our high degree of reliance on fossil fuels (roughly 85% of commercial energy use domestically and globally) and the difficulties—technical, economic, and social—of large-scale use of alternative options (like nuclear and renewables), the ability to use fossil energy while avoiding greenhouse gas emissions is a potentially attractive alternative that needs to be carefully studied. Coal-based power plants, which contribute about 30% of total U.S. CO₂ emissions, are the principal targets for this type of CO₂ control technology (3–5).

Technology Options for CO₂ Capture. A wide range of technologies currently exist for separation and capture of CO₂ from gas streams (Figure 1), although they have not been designed for power-plant-scale operations (6). They are based on different physical and chemical processes including absorption, adsorption, membranes, and cryogenics (7–11). The choice of a suitable technology depends on the characteristics of the flue gas stream, which depend mainly on the power plant technology. Future coal-based power plants may be designed to capture CO₂ before combustion (using coal gasification systems), or they may employ pure oxygen combustion instead of air to obtain a concentrated CO₂ stream for treatment. Figure 2 shows the variety of power plant fuels and technologies that affect the choice of CO₂ capture systems.

Options for CO₂ Sequestration. Once the CO₂ is captured, it needs to be securely stored (sequestered). Again, there are a range of options potentially available. Geologic formations including deep saline reservoirs, depleted oil and gas wells, and unmineable coal seams are some of the potentially attractive disposal sites (12–14). Ocean disposal is another option being studied (15, 16). The distance to a secure storage site and the availability and cost of transportation infrastructure also affect the choice of disposal option. In general, studies indicate that geologic formations are the most plentiful and attractive option for U.S. power plants (17). While the economic costs of CO₂ storage appear to be low, its social and political acceptability are not yet clear, especially with regard to ocean sequestration.

Scope of This Study

This research is motivated by a desire to better understand the technological options for CO₂ capture and sequestration and their possible role in climate mitigation policy. Because the topic is fairly new, some of the key research questions that need to be addressed include the following: What kind of technologies may be used for capture and storage of CO₂? What are the key parameters that affect the performance, cost and environmental acceptability of different options? How do the alternative options compare in terms of these considerations? What are the uncertainties associated with different options? What are the benefits of R&D to reduce key uncertainties?

To begin addressing such questions, this paper focuses on current coal combustion systems. Today the 300 GW of coal-fired power generation capacity in the U.S. provides 51% of all power generation and accounts for 79% of carbon emissions coming from electric utilities. Even with the expected growth in natural gas for new generating capacity, coal’s share of the electricity supply is still projected to be about 44%in 2020 and higher in absolute capacity compared to today (18). Thus, any new policies to significantly reduce CO₂ emissions during the next two or three decades must consider not only the technology options for new power plants (which is the case typically discussed in the literature) but also the retrofitting of existing coal plants which will continue to operate for several decades to come. Such medium-term intervention to reduce CO₂ emissions has received relatively little attention to date. Hence, the present study examines the feasibility of postcombustion carbon capture at existing power plants as well as new facilities.