Study: 'Waste heat' may economize CO2 capture

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HOUSTON -- (March 28, 2013) -- In some of the first results from a federally funded initiative to find new ways of capturing carbon dioxide (CO2) from coal-fired power plants, Rice University scientists have found that CO2 can be removed more economically using "waste" heat -- low-grade steam that cannot be used to produce electricity. The find is significant because capturing CO2 with conventional technology is an energy-intensive process that can consume as much as one-quarter of the high-pressure steam that plants use to produce electricity.

"This is just the first step in our effort to better engineer a process for capturing CO2 from flue gas at power plants," said George Hirasaki, the lead researcher of Rice's CO2-capture research team. The researchers hope to reduce the costs of CO2 capture by creating an integrated reaction column that uses waste heat, engineered materials and optimized components. Hirasaki's team was one of 16 chosen by the Department of Energy (DOE) in 2011 to develop innovative techniques for reducing greenhouse gas emissions from power plants.

The team's first findings appear in two new studies that are available online this month in the International Journal of Greenhouse Gas Control.

Power plants fired by coal and natural gas account for about half of the CO2 that humans add to the atmosphere each year; these power plants are prime candidates for new technology that captures CO2 before it goes up in smoke. Each of these plants makes electricity by boiling water to create steam to run electric turbines. But not all steam is equal. Some steam has insufficient energy to run a turbine. This is often referred to as "waste" heat, although the term is something of misnomer because low-grade steam is often put to various uses around a plant. Rice's new study found that in cases where waste is available, it may be used to capture CO2.

Hirasaki, Rice's A.J. Hartsook Professor of Chemical and Biomolecular Engineering, said employing waste heat is just one example of a number of ways that Rice's team is looking to improve upon a tried-and-true technology for CO2 capture. That technology -- a two-phase chemical process -- has been used for decades to remove naturally occurring CO2 from natural gas.

In the first phase of the process, gas is piped upward through a vertical column while an ammonia-like liquid called amine flows down through the column. The liquid amine captures CO2 and drains away while the purified natural gas bubbles out the top of the column. In the second phase of the process, the CO2-laden amine is recycled with heat, which drives off the CO2.

"The CO2 that comes out of the ground with natural gas is under high pressure, while the CO2 at power plants is not," Hirasaki said. "There's also a greater volume of CO2 per unit mass at a power plant than at a natural gas well. For these reasons and others, the amine process must be re-engineered if it is to be cost-effective for CO2 capture at power plants."

A major challenge in adapting two-phase amine processing for power plants is the amount of heat required to recycle the amine in the second phase of the process. Using existing amine processing technology at power plants is impractical, because amine recycling would require as much as one-quarter of the high-pressure steam that could otherwise be used to drive turbines and make electricity, Hirasaki said. This phenomenon is known as "parasitic" power loss, and it will drive up the cost of electricity by lowering the amount of electricity a plant can produce for sale.

"It has been estimated that the use of current technology for CO2 capture would drive up the cost of electricity by 70 to 100 percent," said Rice graduate student Sumedh Warudkar, a co-investigator on the Rice University team. "In our study, we examined whether it would be possible to improve on that by using lower-value steam to run the amine recyclers."

To test this idea, Warudkar used a software package that's commonly used to model industrial chemical processes. One variable he tested was tailoring the chemical formulation of the liquid amine solution. Other variables included the type of steam used, and the size and pressure of the reactor -- the chamber where the flue gas flows past the amine solution.

"There's a great deal of optimization that needs to take place," Warudkar said. "The question is, What is the optimal amine formula and the optimal reactor design and pressure for removing CO2 with low-value steam? There isn't one correct answer. For example, we have developed a process in which the gas absorption and solvent heating occurs in a single vessel instead of two separate ones, as is currently practiced. We think combining the processes might bring us some savings. But there are always trade-offs. The Department of Energy wants us to investigate how our process compares with what's already on the market, and these first two studies are the first step because they will help us identify an optimal set of operating conditions for our process."

The results are encouraging. The research suggests that two elements of Rice's design -- optimized amine formulation and the use of waste heat -- can reduce parasitic power loss from about 35 percent to around 25 percent.

Additional research is under way to develop and test novel materials and a single integrated column that the team hopes can further economize CO2 capture by increasing efficiency and reducing parasitic power loss.

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