Reply:

We were glad to receive the comments of Dr. Lowell and to learn about the interest in our article "A Superstructure-Based Optimal Synthesis of PSA Cycles for Post-Combustion CO_2 Capture".[1] In the development of process synthesis tools for challenging new problems like CO_2 capture, it is essential to get feedback from individuals concerned about the real world implications. Based on his concerns, we offer the following response.

1. In Case 3 of our study,[1] a PSA cycle is designed to achieve a specified CO_2 recovery, while minimizing power consumption per tonne of CO_2 captured. The specified 85% CO_2 recovery and corresponding power requirement of 465 kWh/tonne CO_2, is independent of the amount of overall power generated by the pulverized coal (PC) plant.

In Dr. Lowell's letter, assuming the calculation of CO_2 emissions from a 500 MW PC plant without CO_2 capture is correct and equal to 614 tonnes CO_2/h, we agree with the calculated ratio of energy needed for carbon capture, $\eta = 48.55\%$. We also agree that when considering CO_2 capture, the PC plant would need to be scaled up in order to maintain a net power of 500 MW. However, we do not agree with the calculations that are presented for a scaled-up PC plant with CO_2 capture. These calculations incorrectly assume that the CO_2 recovery is reduced from 85 to 71%.

For a PC plant with CO_2 capture and a net 500 MW capacity, the overall power plant capacity would need to be: $(1-\eta)\times P = 500\ MW \rightarrow P = 972\ MW$. In this case, the amount of CO_2 released would also be more, $(614 \times 972.8/500 =)$ 1194.5 tonnes CO_2/h. Allowing 48.55% of 972 MW (= 472 MW) for CO_2 capture leads to $(472 \times 1000/465 =)$ 1015 tonnes CO_2/h, or $(1015/1194.5 =)$ 85% of the overall CO_2 released. So, recovery still remains at 85%. As expected, this capture level is independent of the power plant capacity.

2. Using high-sulfur eastern coal, Dr. Lowell shows a lower energy penalty (38% of total PC plant output) for CO_2 capture using PSA. To deal with other coals, we also consider a comparison in a recent NETL report[2], (p 4, Exhibit ES-2) for PC plants with bituminous coal with 71% carbon and 2.82% sulfur (dry basis). For a 583 MW PC plant (Case 9 in Exhibit), the amount of CO_2 released is 1,038,110 lb/h = 471 tonnes CO_2/h. For this number, the energy consumption for PSA comes out to be $(0.85 \times 471 \times 465/1000 =)$ 186 MW. So, the energy penalty is 186/583 = 31.9%, which is still lower.

3. We state[1] that energy requirements for absorption processes range from 765–950 kWh/tonne of CO_2 captured (excluding energy requirement for CO_2 compression). As cited,[1] these figures were taken from an IPCC report[3] (p 117), which states "Values for the heat requirement for the leading absorption technologies are between 2.7 and 3.3 GJ/tonne CO_2, depending on the solvent process. Typical values for the electricity requirement are between 0.06 and 0.11 GJ/tonne CO_2 for post-combustion capture in coal-fired power plants."

The combined energy requirement (before compression) of 2.76 – 3.43 GJ/tonne CO_2 translates to 767–947 kWh/tonne CO_2.

While our Case 3 results for PSA show a lower energy penalty than the absorption technologies,[3] we agree that the energy requirements for PSA are high, and CO_2 compression costs still need to be considered. On the other hand, in our study[1] we have considered only a standard sorbent, Zeolite 13X. As we cited, a number of higher performing sorbents, such as K-promoted Hydrotalcite, are also being investigated (see, e.g. Ref. 4). Instead, the goal of our study was to develop and apply a superstructure optimization formulation for the design of PSA cycles with CO_2 capture as an application. This approach can be applied to a wide variety of sorbents, as well as feed and product specifications. We also note that a similar optimization approach was recently applied to *precombustion CO_2 capture* in IGCC processes,[5] where the energy requirements for PSA were *only 46.8 kWh/tonne CO_2 captured, an order of magnitude less*.

4. Finally we note that while energy requirements and penalties may be useful to compare alternate technologies for carbon capture, it is misleading to assume that these requirements should directly subtract from the capacity of the power plant. For instance, as the major energy requirement for absorption is from heat, this could be extracted from waste heat through heat and power integration of the utility system. As a result, energy evaluation of any carbon capture technology requires an analysis of integration with the heat and power system. A number of integration options are described in Ref. 3 along with literature references.

Moreover, there is extensive process synthesis literature (see, e.g., Ref. 6) that provides efficient, systematic methods to carry out this task. While this is beyond the scope of our study[1], the eventual validation of a particular technology must require heat and power integration with the power plant, preferably using advanced process synthesis tools.

Literature Cited

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