Strategies for reducing the cost of air capture

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Economically viable technologies to remove carbon dioxide from ambient air, either for carbon dioxide storage or carbon dioxide reuse, could be game-changing innovations. Even though air capture is technically feasible, opinions are divided on whether the necessary cost reductions are possible. A leading argument against the economic feasibility of direct air capture is Sherwood's observation that the cost of separation tends to scale linearly in the dilution (Sherwood's Rule). Extending the cost of separating metals from ores or impurities from flue gas would result in unacceptable carbon dioxide capture costs and would render air capture irrelevant. Furthermore, an APS study of direct air capture concluded based on reviewing a specific implementation of air capture that its first-of-a-kind cost of $600/ton of CO_2 gives little hope that air capture can ever be implemented in a cost-effective manner. This cost is, however, less than Sherwood's Rule would suggest. This paper outlines a broad based strategy to avoid the restrictions of Sherwood's Rule and to take advantage of the huge cost reductions typical in mass production. Lastly, it outlines approaches to direct capture of carbon dioxide from ambient air that minimize the energy cost of the regeneration process and establishes figures of merit for sorbent systems that can operate at affordable costs. We show that Sherwood's Rule often applies because the cost of the separation process is dominated by the first step in the separation process. Since this step involves all input material, its cost naturally scales linearly in the dilution. Subsequent steps typically add much smaller costs, but these additional costs generally do not follow the same scaling law. By lowering the cost of the first step, it is possible to break Sherwood's Rule. We will show how this can be done for air capture and give examples of other separation processes where it has been done successfully. Furthermore, we note that mass manufacturing has been able to reduce the cost of many processes well below that of the first-of-a-kind implementation. For example, photovoltaic systems today are roughly one hundred times cheaper than they were in the 1960s. Thus, a starting point of $600/ton should be seen as encouraging rather than discouraging. Applying a mass production paradigm to air capture has a better chance of driving cost down than staying within the confines of a classic utility model that relies on ever larger unit size. This observation has important implications for the process design. Rather than scaling up unit size, the emphasis shifts toward modular designs that can be scaled in numbers, and that are by design mass producible. However, small units cannot demand much human attention as personnel cost becomes prohibitive if amortized over small outputs. This will focus the design effort on automation and reliability. Cost reductions will come from learning by doing, which will only happen if the technology is tried out. Fortunately, trying out a technology at the ton-per-day scale requires tens of millions rather than billions of dollars for introducing capture technology on the power plant scale. As a result, small fully-automated units may provide an economic benchmark for large-scale carbon dioxide capture that provides a bound on the cost of climate change mitigation and can also set economic targets for more specialized, but physically easier carbon dioxide capture options.