July 11, 2023

New Developments in Ocean-based CO_2 Removal

Takahiko Tagami
Executive Researcher, Manager, Climate Change Group
Climate Change and Energy Efficiency Unit
The Institute of Energy Economics, Japan

News of ocean-based CO_2 removal plants and research has continued to emerge since the start of this year.

Equatic, which was spun out from the University of California, Los Angeles (UCLA), unveiled a small-scale pilot facility (CO_2 removal capacity of 100kg/day) in the Port of Los Angeles on April 12. The company is also carrying out the demonstration of a pilot plant in Singapore. Captura Corp., which was founded at the California Institute of Technology (Caltech), also announced on May 31 that it will shift a pilot system capable of capturing 100 tons of CO_2 a year from Caltech's Pasadena Campus to the Port of Los Angeles in the coming months, to begin ocean field trials. In February Massachusetts Institute of Technology (MIT) also published a paper proposing a new method for removing CO_2 from the ocean.

Removing CO_2 from seawater has the potential to be a more efficient means of CO_2 removal than direct air capture (DAC) because: (1) with DAC, the CO_2 in the atmosphere first needs to be captured, while in the ocean's case, the CO_2 has already been captured so that step is unnecessary; and (2) the CO_2 concentration of seawater is over 100 times higher than that of the air. If CO_2 is removed from seawater and water with reduced CO_2 is returned to the ocean, that water absorbs further CO_2 from the air.

Electrochemical approaches employ electricity to induce chemical reactions that remove CO_2 from seawater. There are acid approaches and base approaches. With the acid approach, electrolysis is used to create a stream of acid at the anode. This acidic anolyte is then mixed with seawater, the equilibrium of the carbonate system shifts towards CO_2 as a result of the acidification, and CO_2 is released. The acidified, CO_2-lean seawater is then mixed with the base liquid stream and released into the ocean. On the other hand, with the base approach, an electrochemically created base liquid is mixed with seawater to bring about the precipitation of carbonate minerals. The equilibrium of the carbonate system shifts towards CO_2 as a result of the carbonate precipitation, and CO_2 is released. The alkaline seawater is mixed with the acidic stream from electrodialysis, and returned to the ocean.

Captura is employing the acid approach that involves dissociating salt water into an acid and a base through electrodialysis. The acid that is created is added to seawater, and the CO_2 that is released is captured. This acidic, decarbonized seawater is neutralized by introducing the base, and it is then returned to the surface of the ocean to absorb CO_2 from the atmosphere once again. MIT's proposal also employs the acid approach, but is notable for not using membranes in the cells. To begin with, the water is acidified, and the dissolved inorganic bicarbonates are converted to CO_2 molecules and captured as a gas. Next, the water is supplied to a second cell, and a reversed voltage is applied to return alkalinity to the acidic water before it is released into the ocean. MIT proposes reinjecting alkaline water into the sea as a means of addressing the acidification of the ocean. Equatic, meanwhile, is adopting the base approach. Along with generating hydrogen as a result of electrolyzing seawater, its approach fixes the CO_2 to carbonate solids and dissolved inorganic carbon. If it releases these carbonate solids and dissolved inorganic carbon into the sea, the impact on the ocean will need to be considered. The acidic seawater is returned to its original alkalinity level by dissolving alkaline rocks before the water is released into the ocean.

These startups are being provided with a variety of finance. Equatic is receiving funding from Meta's Chan Zuckerberg Initiative, ARPA-E (the Advanced Research Projects Agency-Energy of the Department of Energy) and other sources. Equatic has also concluded pre-purchase agreements for carbon removal and hydrogen supply with global payment solutions provider Stripe and Boeing. In April 2022, Captura was chosen as one of 15 Milestone award-winners in Elon Musk's $100-million XPRIZE Carbon Removal competition. Furthermore, in January 2023, Captura obtained $12 million in funding from Equinor Ventures, Aramco Ventures, Hitachi Ventures and others. Southern California Gas Company provided funding for its recently announced 100 ton/year system. MIT's research also began two years ago based on an ARPA-E grant.

According to the National Academies of Sciences, Engineering, and Medicine's 2021 report, "A Research Strategy for Ocean Carbon Dioxide Removal and Sequestration," the electrochemical process is based on well-known chemistry, but the process is still mid-course in terms of its application to CO_2 removal. The report evaluates the research agenda relating to the electrochemical process as being the reduction of costs, and the environmental impacts. The process in question currently requires a large amount of energy – 1-2.5MWh per ton of CO_2 removed – and costs $150-2,500 per ton of CO_2 removed. Presently, only a few system configurations are being researched, but as a wider exploration of new designs takes place, there is a possibility the cost will be reduced to less than $100/ton of CO_2 removed. Furthermore, the impact on the ecosystem is not well-known, but the impact on the ocean is possibly limited to the discharge points, and it is possible to design water discharge systems that curb the impact on the ocean. The above-mentioned Research Strategy recommends making the implementation of large demonstration-scale projects (1,000kg/day) the focus of the research agenda, in the interest also of reducing costs. The plants I have taken up here have capacities of 100kg/day and around 270kg/day, respectively, and will lead on to projects of that scale. Captura began operating its initial pilot system, which is capable of removing one ton a year, in August 2022, but in one year scaled that up by 100 times. Similarly, Equatic is also scheduled to begin operating a large-scale test plant capable of removing 10 tons/day, in Singapore in late 2024.

Ocean-based CO_2 removal using electrochemical approaches possesses major potential as a negative-emissions technology, in line with DACCS and BECCS. However, the process presents challenges in terms of making it more efficient, and securing renewable energy. Additionally, the potential impact on the ocean also needs to be explored. The examples of funding to startups will also attract attention, as successful examples of shifting from the research and development of technologies, to making them a commercial reality.

Contact: report@tky.ieej.or.jp