CO₂ Capture From Natural Gas Combined Cycle Power Generation Using Carbonate Fuel Cells

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Abstract

Power generation facilities account for a large share of global CO₂ emissions and are also some of the largest point sources, with a typical facility emitting several million tons annually. Thus, they are an obvious target for CO₂ capture. Carbon capture from coal-fired power generation has been the subject of considerable research and several world-scale projects, while capture from natural gas combined cycle (NGCC) power generation has been much less investigated, despite NGCC generation having approximately half of the CO₂ emissions than coal power generation. The majority of R&D in this area has been on the use of amine solvents for CO₂ capture, a process which incurs a significant energy debit because of the steam consumption in the regeneration step.

In this work, we will describe how carbonate fuel cells can be used for CO₂ capture from NGCC facilities without a significant energy debit. The exhaust from the NGCC system is taken as the inlet to the cathode of the fuel cell, with additional natural gas and steam fed to the anode. Within the fuel cell, the natural gas is reformed to hydrogen in the anode, while the CO₂ is combined with oxygen and electrons from the power circuit to make the carbonate ion. The carbonate ion is then transferred through the membrane of the fuel cell to the anode, where the ions react with hydrogen to produce CO₂ and H₂O, and high potential electrons for the power circuit. In this process, additional power is created by the fuel cells, keeping the total efficiency of the system at or near the efficiency of the NGCC system without CO₂ capture.
The carbonate fuel cells function as a highly process-intensified reactor, combining simultaneously four functions into a single system:

1) Autothermal reforming of CH₄ to H₂ and CO₂
2) Oxygen separation from cathode inlet to anode oxidant
3) CO₂ extraction from the cathode inlet to the anode outlet
4) Power generation

In standard operating mode, each of these functions must be balanced against the others, resulting in a fairly tight operating window. However, when used for CO₂ capture, these constraints are liberated, and the operating window is greatly expanded. In particular, the autothermal reforming function can be significantly increased, such that co-production of hydrogen is increased threefold more than normal. This produces a substantial co-product stream of H₂ than can be valued in many ways – as a chemical reagent to a refinery, chemicals plant, or ammonia synthesis facility; as a clean-burning fuel to an existing or new power generation facility; and many others.

This presentation will summarize the current status of this technology. We have obtained substantial proof-of-principle data at the benchtop scale, using single cells of about 50 – 100 W power each. We also have obtained data using a 30 kW fuel cell stack, which is nearly full size in length and width, just limited in height and number of cells. All of this data indicates the technology is feasible, although there are several challenges remaining. Principally, the low CO₂ concentration in the gas turbine exhaust reduces the performance of the fuel cells; progress towards improving the fuel cell at very low CO₂ concentrations will be reported. We will also describe the 3 MW demonstration facility at a coal-fired power plant in Alabama.