Coal-Based Nanoporous Sorbent

primary project goal

The project goal is to develop a sustainable and cost-efficient nanoporous sorbent derived from coal for direct air capture (DAC) of carbon dioxide (CO_2). The design of the sorbent involves the use of domestic coal converted into nanoporous CO_2-adsorbent material with high surface area and metal oxide functionalities.

technical goals

- Identify and synthesize a carbon sorbent material with the potential of achieving a CO_2 uptake of 4–7 wt% CO_2 from simulated air with a CO_2 concentration of 400 parts per million (ppm). Degradation target is below 5% under inert sweep gas conditions.
- Optimize sorbent formulation parameters and demonstrate CO_2 uptake of 7 wt% CO_2 in a multi-cycle test. Heat of adsorption target is 50–70 kilojoules (kJ)/mol.
- Downselect sorbent, scale-up the sorbent, and complete full gas adsorption and gas-breakthrough testing for simulated CO_2/air feed gas. Expected kinetics are 4–7 wt% CO_2 uptake and a degradation milestone below 10% over the cycles.

technical content

DAC has attracted ever-increasing interest due to its potential to contribute toward net-negative CO_2 emission goals. DAC faces major challenges with removing CO_2 from an ultra-dilute stream (~400 ppm CO_2 in air) and being more costly to separate CO_2 compared to more concentrated systems (like flue gases). Solid sorbents with strong CO_2 chemical binding are one of the main DAC technical approaches. Amine-based sorbents have been demonstrated in pilot plants (like Climeworks and Global Thermostat) but are challenged by massive CO_2 capture costs. Amine-functionalized adsorbents on porous solid supports such as zeolites, mesoporous silica, metal-organic frameworks (MOFs), and porous organic polymers (POPs) are intensively studied for flue gas. However, low CO_2 uptake, high sorbent cost, and long-term stability have been major drawbacks, along with inherent amine evaporation and oxidation. Overall, the sorbents for DAC are in their infancy. There is a need for new sorbents with desirable characteristics (i.e., high CO_2 adsorption capacity and stable performance in presence of water and oxygen) and new processes that can reduce CO_2 capture costs to achieve successful DAC. The National Energy Technology Laboratory (NETL) has been studying an extensive portfolio of coal conversions for clean energy and sorbents for CO_2 capture applications. The capability to create high surface area and adjust pore size in sorbents is a prime expertise that has developed over the years. Many porous adsorbents with high surface area and targeted functional groups to reach more efficient CO_2 capture have been developed.

Functionalization of porous sorbents with CO_2-attractive groups is an imperative task to enhance the CO_2 adsorption at very low concentrations. The project team is using low-cost domestic coals, which are suitable for generating novel nanoporous carbon sorbents with high surface area and porosity and functionalized metal oxides. The team creates high porosity (micro/mesoporous)

program area:
Carbon Dioxide Removal

ending scale:
Laboratory Scale

application:
Direct Air Capture

key technology:
Sorbents

project focus:
Nanoporous CO_2 Sorbent Derived from Coal

participant:
National Energy Technology Laboratory–Research and Innovation Center

project number:
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predecessor project:
N/A

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and surface area within the carbon by treating with a base facilitating pyrolysis. The carbon is then functionalized with metal oxides using a unique method. The metal oxides introduced to the carbon enhances the capture selectivity toward CO_2, which can be improved further in the presence of moisture. The sorbent design can easily be scaled up to kilogram levels at low cost due to its simple preparation method, which doesn't involve any expensive catalysts or template use. The high surface area property of carbon brings the advantage of well-distributed metal oxides throughout the sorbent. High CO_2 uptake capacity (4–7 wt%), at even 400 ppm, can be achieved with this design. While abundancy and low cost of coal are expected to further lower the total sorbent cost, the unique functionalization strategy can tailor the CO_2 interaction potential of the sorbent. This sorbent design has the ability to tune the porosity and the level of metal oxide functionalization. Therefore, optimum sorbent regenerability can be achieved and the heat requirement for the regeneration of the sorbent can be minimized. The team is collaborating with a computational team at NETL to optimize CO_2 sorption properties of the sorbent. Computed properties of the carbon, such as pore structure and the nature of the CO_2 interaction with the functional groups, are used to guide experiments to optimize the sorbent for the DAC process. It is also noteworthy that sorbent stability is very important for sustainable DAC. The proposed sorbent will exhibit high stability and mitigate major stability problems (i.e., pores collapsing over time and amine leaching) associated with MOFs and silica-based sorbents, respectively. The sorbent may also be fabricated to hydrophobic materials to be used in high-humidity air.

technology advantages

- Sorbent design can easily be scaled up to kilogram levels at low cost due to its simple preparation method.
- High surface area of carbon facilitates distribution of metal oxides throughout the sorbent.
- Abundancy and low cost of coal are expected to lower the total sorbent cost.
- Ability to tune the porosity and the level of metal oxide functionalization to optimize sorbent regenerability and minimize regeneration heat requirement.
- Sorbent exhibits high stability.

R&D challenges

- Creating high surface area and porosity (micro/mesoporous) in carbon.
- Effective functionalization of the sorbent with metal oxide groups.
- Ability to adjust porosity and the level of functional groups in carbon.
- Successful computational study to optimize the sorbent properties.
- Achieving high CO_2 uptake capacity between 4–7 wt% CO_2 at 400 ppm.
- Cost-effective CO_2 regeneration.

status

Porous carbon sorbents from coal with high porosity (micro/mesoporous) were synthesized and functionalized with metal oxide, which was confirmed by Fourier transform infrared spectroscopy (FTIR) analysis. Functionalization and testing are ongoing to optimize the sorbent performance.

available reports/technical papers/presentations

N/A.