the ENERGY lab

PROJECT FACTS

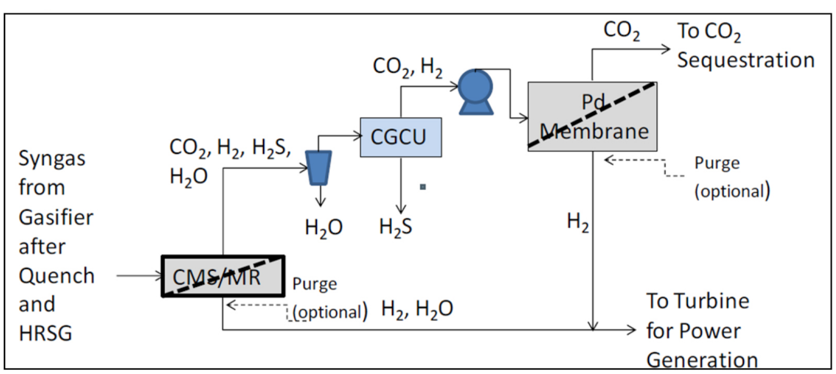
Carbon Capture

Robust and Energy Efficient Dual-Stage Membrane-Based Process for Enhanced CO_2 Capture

Background

The mission of the U.S. Department of Energy Office of Fossil Energy's (DOE FE) Carbon Capture Research & Development (R&D) Program, implemented through the National Energy Technology Laboratory (NETL), is to develop innovative carbon dioxide (CO_2) emissions control technologies for fossil fuel-based power plants. The Carbon Capture R&D Program portfolio of pre- and post-combustion CO_2 emissions control technologies and related CO_2 compression is focused on advancing technological options for new and existing power plants to enable cost-effective CO_2 capture for beneficial use or storage of CO_2 and ensure that the United States will continue to have access to safe, reliable, and affordable energy from fossil fuels. The DOE FE/NETL goal is to demonstrate second-generation technologies that can capture 90 percent of the CO_2 at less than $40 per metric ton (tonne) in the 2020–2025 timeframe. DOE is also committed to extending R&D support to even more advanced transformational carbon capture technologies that will increase competitiveness of fossil-based energy systems beyond 2035.

Pre-combustion CO_2 capture technologies are applicable to integrated gasification combined cycle (IGCC) power plants, where solid fuel is converted into gaseous components (synthesis gas, or syngas) by applying heat under pressure in the presence of steam and oxygen. The CO_2 is captured from the syngas before combustion and power production occurs. Pre-combustion carbon separation and capture is relatively simple and less expensive compared to post-combustion capture as it has a greater driving force with the processed syngas at a much lower volume, at a higher pressure, and containing a higher concentration of CO_2. Novel processes combining two or more pre-combustion capture technologies may take advantage of system synergies to increase efficiency and lower operating and capital costs.



Novel dual-stage process scheme using a CMS membrane as a membrane reactor for primary hydrogen recovery and a Pd-based membrane for additional hydrogen recovery.

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PROJECT DURATION

Start Date	**End Date**
10/01/2013	09/30/2016

COST

Total Project Value
$2,500,029

DOE/Non-DOE Share
$2,000,023/$500,006

PROJECT NUMBER

FE0013064

U.S. DEPARTMENT OF ENERGY

Project Description

Media and Process Technology Inc. has partnered with the University of Southern California and Technip USA to conduct bench-scale testing of an innovative process scheme that combines two membrane technologies to accomplish cost-effective pre-combustion CO_2 capture. The dual-stage process comprises (1) hydrogen-selective carbon molecular sieve membranes (CMSM) for water-gas-shift (WGS) reaction in a membrane reactor (MR) with hydrogen recovery in tandem with (2) palladium (Pd)-based membranes for efficient residual hydrogen recovery from the WGS/MR retentate with CO_2 capture. The novel process scheme was based on previous successful research that validated key performance aspects of the individual components. The two individual membrane processes were tested at laboratory scale on simulated syngas and at the National Carbon Capture Center (NCCC) using actual coal- and biomass-derived syngas.

The project team will test the dual-stage process on simulated syngas mixtures in a bench-scale system, followed by testing with real syngas for performance and long-term operation stability. Coal-derived syngas, after quenching and particulate removal, will undergo tar and contaminant removal, carbon monoxide conversion via WGS with a sour shift catalyst, and hydrogen separation in a WGS/MR. The bulk of the hydrogen produced (with purity adequate for downstream power generation) will be recovered in the permeate stream of this novel WGS/MR. The retentate stream (containing the residual hydrogen and the bulk of CO_2 produced), after undergoing a conventional cold gas clean-up for the removal of tar and contaminants, will be sent for CO_2 compression for storage. Through the CO_2 compression train, the residual hydrogen will be further recovered using a highly-selective Pd-based membrane. Thus, a high degree of hydrogen (and consequently CO_2) recovery can be achieved with the dual-stage membrane process.

The dual-stage membrane process achieves high hydrogen recovery and CO_2 capture efficiency with minimal or no parasitic energy consumption. Such multi-stage processes are commonly practiced by the membrane industry for higher recovery requirements, but a unique advantage of this process is that it incurs no additional energy penalty or added capital costs for the re-compression needed for the second stage. Based upon a preliminary engineering analysis of this innovative process technology, a roughly 50 percent reduction in cost can be achieved in comparison with the current state-of-the-art process. This anticipated cost reduction shows promise toward meeting the overall Carbon Capture Program performance goals.

Primary Project Goal

The primary project goal is to perform bench-scale (0.01MWe) testing to validate an innovative dual-stage membrane process for pre-combustion carbon capture and verify that it can meet the DOE performance goal to demonstrate second-generation technologies that can capture 90 percent of the CO_2 at less than $40 per tonne in the 2020–2025 timeframe.

Objectives

The project objectives are to (1) construct a bench-scale unit for the experimental verification of the CMSM and Pd membrane process; (2) conduct laboratory testing with simulated syngas mixtures; (3) verify the process further with bench-scale testing using real syngas at a testing facility; and (4) detailed economic, engineering, and environmental analysis of the process design.

Planned Activities

- Upgrade the existing WGS/MR laboratory-scale system to operate over a broader range of conditions relevant to those planned for the bench-scale system and, specifically, for temperatures up to 350 degrees Celsius and pressures of up to 200 pounds per square inch gauge (psig).
- Operate the laboratory-scale system using synthetic syngas containing simulated tar and organic vapors to investigate the performance of the CMSM under more severe operating conditions and determine the impact on both membranes and catalysts.
- Investigate the ability of Pd-based membranes to recover hydrogen from synthetic gas mixtures with compositions and pressure that match those of the reject stream from the WGS/MR after being subjected to cold gas clean-up and recompression.
- Validate the existing mathematical model for the new set of operating conditions and use it to reliably predict the performance of the bench-scale WGS/MR for the novel process scheme prior to the initiation of testing and to guide the design and construction of the bench-scale system.
- Perform in-house experimental testing to evaluate gas permeation and catalytic reaction performance under higher pressures (up to 600 psig).
- Design and fabricate a bench-scale CMSM-WGS/MR for field-testing.
- Prepare a Pd-based membrane separator for second stage hydrogen recovery.
- Conduct field testing of the CMSM-WGS/MR and Pd-based membrane gas separators at the testing facility using raw coal-derived syngas, and operate the combined system continuously for two months to evaluate performance stability.
- Perform techno-economic and environmental, health, and safety analyses for the process.

Accomplishments

Project awarded in September 2013.

Benefits

The project outcome, resulting from both bench-scale experimental studies and process simulations, will be a field validation of the performance and efficiency improvement of the dual-stage membrane process scheme for CO_2 capture. The results of this project will enable further advancement of the technology to pilot- and full-scale development as the next step to meet DOE cost and performance objectives.