the ENERGY lab

PROJECT FACTS

Gasification Technologies

Advanced Hydrogen Transport Membranes for Coal Gasification

Background

Technologies for pre-combustion carbon dioxide (CO_2) capture and sequestration and economical hydrogen (H_2) production will contribute to the development of a stable and sustainable U.S. energy sector. The integrated gasification combined cycle (IGCC) process can be used to co-produce synthesis gas (syngas), electricity, H_2, fuels, and chemicals from coal and coal/biomass-mixtures in an environmentally responsible manner. The hydrogen transport membrane (HTM) system separates H_2 from coal-derived syngas after it has been produced via the water-gas shift (WGS) reaction, which is a key part of this process. The application of H_2 separation technology can facilitate the production of high-purity H_2 from IGCC. In addition, CO_2 produced from a WGS membrane reactor is under high pressure, suitable for sequestration or use in enhanced oil recovery. The advantages of using an HTM are the high purity level of the H_2 produced and that CO_2 is produced at elevated pressure.

The U.S. Department of Energy (DOE) Gasification Program is developing technologies with the potential to improve IGCC economics (cost, efficiency, and environmental performance) so that electric power can be produced with greater than 90 percent carbon capture at less than 10 percent increase in the cost of electricity. The DOE's National Energy Technology Laboratory (NETL) is partnering with Praxair, Inc. (Praxair) to develop HTM to separate H_2 from coal-derived syngas. Development of cheaper and more durable dense metal membranes (currently based on noble metals such as palladium and platinum) is needed for generation of pure H_2 from coal, suitable for specially designed turbines or fuel cells.

Project Description

The focus of this project is to demonstrate the separation of hydrogen from coal or coal-biomass derived syngas via membranes at the pre-engineering/pilot scale. In Phase I, the project team has designed, constructed, and tested membranes with an operating gasifier and in simulated syngas mixtures. The goal to produce 2 pounds per day (lb/day) of hydrogen from the operating gasifier was accomplished in Phase I. Phase II is to demonstrate scaled up membrane performance and design, build and test a hydrogen transport membrane module to separate at least 50 lb/day of H_2 from an operating gasifier. A performance goal for this project is to produce a multi-tube design containing 50 to 100 tubes. Module performance data will be used to conduct a techo-economic evaluation of HTM gasifier processes to determine the commercial benefit of HTM. The project team will also develop methods to produce commercial quantities of substrates and membranes at reasonable cost, which are critical for any future introduction of the technology into an industrial application. A membrane module will be tested in the laboratory using a simulated syngas. Ultimately, the membrane module will be incorporated downstream of an existing small gasifier to evaluate membrane performance on coal-derived syngas.

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PARTNERS

Colorado School of Mines

T3 Scientific LLC

University of North Dakota Energy and Environmental Research Center (UNDEERC)

PROJECT DURATION

Start Date	End Date
10/01/2010	09/30/2015

COST

Total Project Value
$8,579,604

DOE/Non-DOE Share
$6,005,772 / $2,573,882

Praxair will synthesize and fabricate HTMs based on prior work done by Praxair and Colorado School of Mines (CSM). Praxair will identify and evaluate a suitable high-temperature, contaminant resistant HTM; fabricate and install it in a proof-of-concept reactor connected to an operating coal gasifier; and test the membrane reactor for separating at least 50 lb/day of H_2 from the coal-derived syngas. The team will evaluate membrane performance of flux, sulfur tolerance, and H_2 purity under syngas conditions expected from coal gasification. Tests will be conducted using existing reactor systems that have been modified to accommodate hydrogen sulfide (H_2S) testing.

Figure 1. Multi-tube hydrogen purifier.

Praxair will conduct engineering studies to evaluate the overall cost of power and H_2 produced from different coal gasification process configurations using HTM. The team will use results from Phase I testing to estimate the cost for membranes and membrane separator reactor(s) at a commercial scale. Sensitivity studies to be performed around the membrane reactor box of the plant process flow configurations will include nitrogen (N_2) sweep, process integration and intensification, and alternate sweep streams for H_2 production.

Goal and Objectives

The primary goal of this two-phase project is to demonstrate the separation of H_2 from coal or coal-biomass derived syngas via membranes at the pre-engineering/pilot scale to enable the use of coal to produce power without significant CO_2 emissions in IGCC power plants. The objective of Phase I was to demonstrate the feasibility of separating H_2 from coal and coal-biomass derived syngas on a small scale.

The objectives of Phase II are to (1) demonstrate scaled-up membrane performance, (2) design an HTM module to separate at least 50 lb/day of hydrogen from an operating gasifier, (3) build the module, (4) demonstrate module performance when integrated with an operating gasifier, (5) scale up the optimized membrane manufacturing process developed in Phase I, and (6) optimize the process for producing hydrogen from coal or coal-biomass derived syngas. Another important objective of Phase II is to improve gas phase mixing in the reactor to ensure that it does not limit hydrogen yield and recovery.

Accomplishments

The project team has fabricated various palladium (Pd), palladium-silver (Pd-Ag), palladium-platinum (Pt-Pd), and palladium-gold (Pd-Au) membranes and measured H_2 fluxes as a function of pressure, temperature, and membrane preparation conditions.

The project team has reported the following laboratory scale accomplishments:

- Alloys with good sulfur resistance and high flux have been identified, produced, and tested with and without sulfur
- Twelve membranes were made using Pd-Au alloy and were coated with MembraGuard™ from T3 Scientific.
- The membranes successfully demonstrated a stable H_2 flux at pressure differences of 200 pounds per square inch and temperatures above 400 degrees Celsius.
- Shown that MembraGuard coating significantly improved resistance to high sulfur content (up to 200ppm)
- Produced membranes up to two feet long with substrate manufacturing process scalable to larger diameters and lengths.
- Shown that increased alloy metal content improves sulfur resistance regardless of fabrication technique (for the range tested) and that ternary alloy component improves sulfur tolerance.
- Two lb/day of hydrogen was produced by each membrane module.

Praxair has built a new membrane reactor to accommodate testing of membranes in the presence of sulfur-containing gases. CSM, a partner in the project, has built a small-scale gasifier and membrane test unit connected to the gasifier to enable testing in coal-derived syngas at a small scale before larger-scale demonstration testing at the University of North Dakota's Energy and Environmental Research Center (EERC). Three demonstration tests conducted at EERC in Phase I confirmed the feasibility of separating H_2 from coal and coal-biomass derived syngas. Each membrane module tested was connected to a gasification stream with a feed composition mix of H_2, N_2, methane, carbon monoxide, and CO_2 combined with H_2S, carbonyl sulfide, and other trace contaminants. Further testing at EERC will be done using a larger gasifier with higher gas flow.

Figure 2. Membranes shown (from top to bottom): ceramic support, activated and coated with palladium oxide, plated with palladium, and plated with palladium and gold.

Benefits

The use of HTM could improve the process by producing hydrogen at high purity while maintaining the pressure of the separated CO_2 stream to facilitate capture for sequestration or enhanced oil and gas recovery. The eventual impact of this improvement is a reduction in the cost of H_2 production from a wide variety of sources, including coal, natural gas, and oil. This technology will provide a viable step forward for the H_2 fueled energy economy by using abundant domestic coal feedstocks.