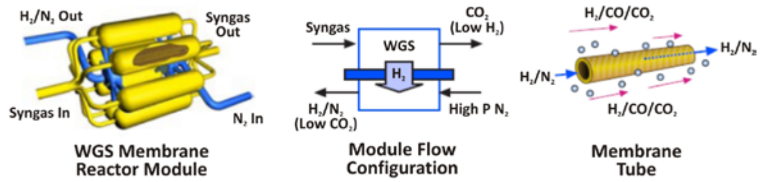
Process Intensification with Integrated Water-Gas-Shift Membrane Reactor

Hydrogen-Selective Membranes for High-Pressure Hydrogen Separation

This project will develop hydrogen-selective membranes for an innovative water-gas-shift reactor that improves gas separation efficiency, enabling reduced energy use and greenhouse gas emissions.



Reactor concept (left). Flow diagram (middle): Hydrogen (H_2) permeates the membrane where nitrogen (N_2) sweeps the gas to produce a high-pressure H_2/N_2 gas stream. Membrane diagram (right): The H_2-selective membrane allows the continuous removal of the H_2 produced in the water-gas-shift (WGS) reaction. This allows for the near-complete conversion of carbon monoxide (CO) to carbon dioxide (CO_2) and for the separation of H_2 from CO_2.

Image Courtesy of General Electric Company, Western Research Institute, and Idaho National Laboratory.

Introduction

The goal of process intensification is to reduce the equipment footprint, energy consumption, and environmental impact of manufacturing processes.

One candidate for process intensification is gasification, a common method by which hydrocarbon feedstocks such as coal, biomass, and organic waste are reacted with a controlled amount of oxygen and steam to produce synthesis gas (syngas), which is composed primarily of hydrogen (H_2) and carbon monoxide (CO).

The water-gas-shift (WGS) reaction is often applied to these syngas streams next, converting the CO and added steam to carbon dioxide (CO_2) and H_2.

The shifted stream is then cleaned of CO_2 in a gas-separation stage. Gas separation allows H_2 to be isolated from syngas and used as a clean fuel or feedstock in chemical production. The leftover CO_2 can be captured and used in chemical production or sequestered, rather than released into the atmosphere.

Conventional options for CO_2 removal, such as solvent-based absorption, are energy intensive and require cooling of syngas. For many applications, the newly purified H_2 must be re-pressurized and/or reheated, imposing additional energy penalties.

This project will develop an integrated WGS membrane reactor (WGS-MR) that will combine the two processing stages described above and lead to process intensification, reduced energy intensity, and improved separation efficiency.

Benefits for Our Industry and Our Nation

The development of an integrated WGS-MR for hydrogen purification and carbon capture will result in fuel flexibility as well as environmental, energy, and economic benefits. Commercialization of this technology has the potential to achieve the following:

- A reduction in energy use during the separation process by replacing a conventional WGS reactor and CO_2 removal system with a WGS-MR and downsized CO_2 removal unit
- An annual reduction in syngas production energy use of 2.1 trillion Btu and in carbon-equivalent emissions of 24 million metric tons.[1]

Applications in Our Nation's Industry

WGS-MR technology will benefit industries that produce hydrogen from syngas including chemicals production, petroleum refining, metal manufacturing, and power generation.

Particular applications of hydrogen produced from gasification include the following:

- Ammonia production from coal
- Integrated gasification combined cycle (IGCC) coal power plants with CO_2 capture and sequestration

Project Description

The objective of this project is to develop hydrogen-selective membranes for an innovative gas-separation process based on a water-gas-shift membrane reactor (WGS-MR) for the production of hydrogen. Unlike lower-pressure hydrogen produced by other WGS-MR concepts, this high-pressure hydrogen stream can be used directly for the production of chemicals such as ammonia and methanol, combusted for CO_2-free power generation, or further filtered to create high-purity hydrogen.

Barriers

- Developing a high-performance polymer with high hydrogen selectivity and resistance to plasticization from CO and CO_2
- Controlling the fine microstructure of the intermediate support layer while manufacturing the component at scale and reasonable cost

Pathways

General Electric (GE) will perform a detailed system analysis, creating models to establish performance targets for membranes and providing a detailed estimate of energy savings, emissions reductions, and economic benefits.

Idaho National Laboratory (INL) will develop a series of hydrogen-selective materials to determine the correct polymer blends and processing conditions needed to accomplish WGS hydrogen separation.

GE will develop membrane supports with surface microstructures designed to maximize the overall performance of the membrane and the scalable manufacturing processes needed to economically produce them.

Western Research Institute (WRI) will develop a testing capacity with access to its WGS reactor output stream and will perform membrane performance evaluations under realistic conditions.

Milestones

- Model performance of the membrane reactor and system (Completed)
- Develop hydrogen-selective polymer materials
- Develop manufacturing processes for supports with defect-free intermediate layers and membrane modules
- Validate membrane performance under realistic testing conditions
- Demonstrate the economic and environmental benefits of hydrogen produced by the WGS-MR process for ammonia/fertilizer plants

Commercialization

GE has a long history of taking technologies from the conceptual/laboratory stage to the commercial product stage. Upon successful completion of the proposed efforts, the research team will develop a prototype WGS-MR system and demonstrate its performance benefits in an operational gasification facility. The risks associated with scale-up and operability of the integrated WGS-MR such as lifetime, reliability, and impact of process transients will be addressed and mitigated during this phase. Detailed market analysis will also be carried out and the commercialization strategy will be updated.

Following a successful prototype demonstration, the technology will be installed in a phased introduction to several markets: first, coal-to-chemicals (particularly ammonia) production, and later to adjacent markets such as coal-to-power with CO_2 capture and other coal-to-chemicals production markets. Technology penetration into current syngas facilities through retrofitting of existing reactors is also anticipated.

Project Partners

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(endnotes)

1 These numbers were calculated based on a proprietary GE model and the input data from the following sources: A.M. Kunjunny, M.R. Patel, and Navin Nath, “Revamping of CO_2 removal section in Ammonia plant at IFFCO Kalol,” http://www.iffco.nic.in/applications/Brihaspat.nsf/0/c5e6f50205333bdbe52568420026a6ef/$FILE/co2revsp.pdf; Thomas Kreutz et al., “Co-production of Hydrogen, Electricity, and CO_2 from Coal with Commercially Ready Technology,” *International Journal of Hydrogen Energy* 30 (2005):769–784; *Evaluation of Alternate Technologies for Ethylene, Caustic-Chlorine, Ethylene Oxide, Ammonia and Terephthalic Acid*, produced by JVP International, Staten Island, NY (Washington, DC: U.S. Department of Energy, December 2007), http://www1.eere.energy.gov/industry/chemicals/pdfs/alt_tech_pub.pdf.

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