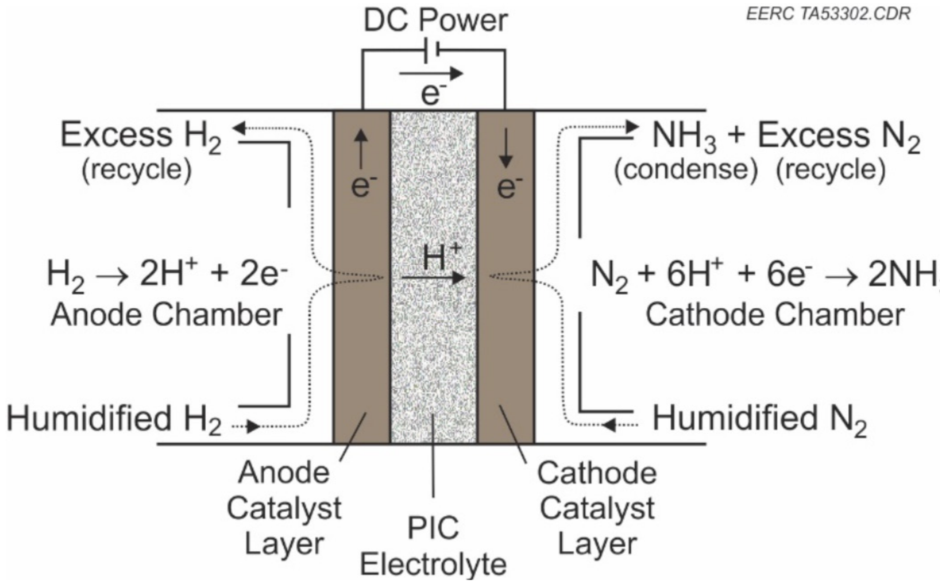
U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Low-Pressure Electrolytic Ammonia (LPEA) Production



Simplified schematic of the polymer-inorganic composite (PIC) proton exchange membrane electrolysis cell proposed for ammonia (NH3) production. *Graphic image courtesy of Energy & Environmental Research Center (EERC)*

Ammonia (NH3) is second most manufactured chemical in the world today, accounting for 1%-2% of global energy consumption. The primary mechanism for NH3 production has been dominated by the Haber-Bosch (HB) process for over a century. Despite extensive optimization efforts, the HB process is highly energy-intensive because it requires high pressures and high recycle rates (as a result of low single-pass NH3 yield) to achieve industrially acceptable NH3 formation rates. Improving or replacing the HB process for NH3 production will help reduce energy consumption, while utilizing hydrogen (H2) more cost-effectively in manufacturing processes.

This project will seek to optimize and demonstrate the improved efficiency of a low-pressure electrolytic NH3 (LPEA) production process (versus the HB process). The LPEA process is based on an innovative polymer-inorganic composite (PIC) high temperature proton exchange membrane (PEM), which is comprised of inorganic proton conductor (IPC) particles composited in an optimal configuration with a high-temperature-compatible polybenzimidazole (PBI) polymer. The LPEA process operates at ambient pressure and a temperature of 300°C, and uses inputs of H2, nitrogen (N2), and electricity to make NH3. The project will begin with laboratory scale fabrication, and optimization of the PIC membrane. The membrane will be tested and optimized with respect to proton conductivity, durability, and current efficiency. The PIC membrane, coupled with selected anode and cathode catalysts, will then be used to build lab-scale membrane–electrode assembly (MEA) configurations. The optimal MEA configuration will then be used as a basis for building a stack of several unit cells that will comprise an LPEA system.

Benefits for Our Industry and Our Nation

The LPEA process under development can improve energy consumption and NH3 formation yield while replacing the conventional HB process. In the LPEA process, temperature has a similar effect to that in the HB process. However, because of its lower operating pressure, the LPEA process is a lower-energy-input alternative because the reaction is driven by electrical work instead of Le Chatelier's principle. Using state-of-the-art LPEA process is expected to have benefits for ammonia production, including:

- A 16% reduction in energy consumption for NH3 production compared to the HB process
- Improved economics for ammonia production and use

Applications in Our Nation's Industry

The LPEA process is expected to have a variety of benefits to the NH3 industry. The primary near-term application is integration into the existing NH3 supply chain by replacing portions of and/or supplementing current HB production infrastructure. This technology can be applied to NH3 fertilizer production for local or regional farmers. In the longer term, the PIC membrane technology could also be applied to high-temperature, high-efficiency water electrolysis for H2 production. LPEA could also be integrated with an electrolysis front end to enable distributed NH3 production using renewable and/or off-peak electricity, which can reduce transportation costs to farmers.

Project Description

The project objective is to demonstrate significant energy reduction for ammonia production using the LPEA process versus traditional high-pressure HB-based processes. The LPEA process is expected to replace HB processes, which have low-single pass yield based on hydrogen conversion. The project outcomes focus on: (a) improving PIC membrane properties; and (b) constructing and optimizing experimental MEAs, along with selected anode and cathode catalysts. The lab-scale prototype should validate a 16% reduction in NH3 production energy input requirements.

Barriers

- Previous PIC membranes were prepared with IPC particles randomly dispersed in a PBI-precursor solution. This method yielded membranes with less-than-optimal proton conductivity due to too much separation and too little contact between IPC particles.
- The mechanical properties of acid-doped PBI membranes decrease significantly with increasing acid-doping level and temperature. Therefore, acid doping alone will not be sufficient to yield a PBI-based PEM with sufficient proton conductivity for the LPEA process.

Pathways

The project is structured to address the key barriers and minimize risk for DOE. The ultimate goal is to demonstrate a LPEA process to replace Haber-Bosch synthesis for NH3 production that can be subsequently commercialized.

The first project pathway will develop and demonstrate lab-scale performance and durability of a high temperature PIC PEM. This will involve identifying and optimizing membrane compositional formulation, physical configuration, and fabrication method based on results of membrane performance and durability testing.

The second pathway will develop an economically viable method for MEA manufacture using the project-developed PIC membrane and project-identified anode and cathode catalysts as inputs. The MEA fabrication method will be optimized based on results of MEA performance and durability testing. The optimized MEA configuration will be incorporated into a multi-cell LPEA system that will be used for evaluating LPEA techno-economic and commercial viability.

Milesones

This three-year project began in June 2018.

- Synthesize at least one PIC membrane with a proton conductivity ≥0.75*10-2 siemens/centimeter (S/cm), gas permeability <10%, <10% thermal decomposition at 300°C; and correlate proton conductivity and durability with composition and structure (2020)
- Demonstrate an LPEA unit cell with a current density ≥0.25 amps/cm2, current efficiency ≥65%, production energy efficiency ≥65%, and ≤0.3% degradation/1000 hours (2021)
- Based on outputs of lab-scale (100-grams/day ammonia production) tests, demonstrate ≥16% reduction in ammonia production energy requirement versus HB requirement of 9.9 MWh/ton of NH3 (2021)

Technology Transition

University of North Dakota's (UND's) Energy & Environmental Research Center (EERC) is partnering with the UND Department of Chemistry, North Dakota State University, Proton OnSite, and the North Dakota Industrial Commission for the design, fabrication and testing of the LPEA process. It is anticipated following successful development, an LPEA pilot-scale demonstration at an appropriate utility site or NH3 plant would be conducted. Following successful demonstration, licensing is envisioned, after which the first LPEA production module would be designed, constructed, and operated. The project team envisions that following a successful pilot-scale demonstration test, commercialization and initial market penetration would progress via demand for incremental production increases at existing NH3 production facilities.

Project Partners

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