Contract No. R-036-045
"Low-Pressure Electrolytic Ammonia Production"
Submitted by: University of North Dakota Energy and Environmental Research Center
Principal Investigator: Ted Aulich

PARTICIPANTS

Sponsor	Cost Share	
U.S. Department of Energy (cash)	$2,497,983	
University of North Dakota Chemistry Department (in-kind)	$ 69,027	
North Dakota State University (in-kind)	$ 120,000	
Proton OnSite (in-kind)	$ 40,000	
Subtotal Cash and In-Kind Cost Share		$2,727,010
North Dakota Industrial Commission	$ 437,000	
Total Project Cost		$3,164,010

Project Schedule – 3 years
Contract Date – 6/21/2018
Start Date – 6/15/2018
Completion Date – 6/30/2021

Project Deliverables:
Quarterly Report: October 31, 2018 ✓
Quarterly Report: January 31, 2019 ✓
Quarterly Report: April 30, 2019 ✓
Quarterly Report: July 31, 2019 ✓
Quarterly Report: October 31, 2019
Go/No-Go Decision Point: December 15, 2019
Quarterly Report: January 31, 2020
Quarterly Report: April 30, 2020
Quarterly Report: July 31, 2020
Quarterly Report: October 31, 2020
Go/No-Go Decision Point: December 15, 2020
Quarterly Report: January 31, 2021
Quarterly Report: April 30, 2021
Final Report: June 30, 2021

OBJECTIVE/STATEMENT OF WORK:
The objective of this project is to optimize the EERC-developed low-pressure electrolytic ammonia (LPEA) production process, with goals of demonstrating LPEA technical and economic viability and compatibility with renewable and/or off-peak electricity. The LPEA process operates at a temperature of 300°C and utilizes inputs of electricity, nitrogen (separated from air), and hydrogen (extracted from natural gas or produced via electrolysis of water) to make ammonia. Unlike traditional commercial ammonia processes that require the use of expensive high operating pressure, the LPEA process operates at ambient pressure, which translates to significantly reduced capital cost, operating cost, input energy requirement, and carbon dioxide emissions. Key to the viability of the LPEA process is a unique EERC–NDSU developed polymer–inorganic composite (PIC) membrane capable of high-efficiency transport of protons at 300°C.

Proposed deliverables include:
- Development and demonstration of a PIC membrane.
- Fabrication of a LPEA system capable of producing 100 g/d of ammonia.
- Demonstration of production using significantly less energy (16% target.)

- LPEA techno-economic analysis and demonstration of economic viability.
- Demonstration of LPEA compatibility and economic viability with renewable energy.

If successful, this project will enable economically viable ammonia production at smaller, distributed-scale plants in response to local/regional demand. It will also accommodate intermittent operation; offering a cost-effective means of monetizing (and storing) renewable energy as ammonia. Production of the PIC membrane offers potential manufacturing opportunities. Additionally, renewable ammonia is increasingly being recognized as a carbon-free transportation fuel and for its potential in blending with coal for reducing CO2 emissions.

STATUS:

The contract has been executed.

October 2018
Status report received. The accomplishments achieved in the time period of July through September include the following:

- Completed and initiated work under research contract agreements with project partners, NDSU and UND Chemistry.
- Completed first milestone, a draft literature search describing commercially available and experimental high-temperature-compatible PBI formulations and their performance and durability attributes and limitations. The literature search is provided as Appendix A.
- Designed and built a state-of-the-art lab-scale polymer–inorganic compositing system for producing core–shell IPC–PBI nanofibers.

More details are available in the full report.

January 2019
Status report received. The accomplishments achieved in the time period of October through December include the following:

- Completed second milestone (Milestone 3.2)—identification and evaluation of at least two PBI formulations—as described in Progress and Status (Task 3).
- Developed an improved IPC solvent (still undergoing optimization) and improved processing conditions, and used these developments to produce improved-quality core–shell (IPC–PBI) nanofibers and nanofiber-based membranes.
- Identified and prioritized four unique catalyst categories/types for empirical evaluation as LPEA cathode catalyst, and synthesized sample of first-priority catalyst material for initial characterization and rotating disk electrode (RDE) testing.
- Developed revised energy consumption target for LPEA process.

More details are available in the full report.

April 2019
Status report received. The accomplishments achieved in the time period of January through March include the following:

- Completed third milestone (Milestone 2.1)—synthesize an IPC material with proton conductivity (PC) ≥1.0 × 10-2 S/cm at 300°C—as described in Progress and Status (Task 2).
- Developed, implemented, and initially evaluated two new approaches for fabrication of IPC–PBI core–shell nanofibers:
    - Airflow-assisted core–shell nanofiber fabrication.
    - Three-step core–shell nanofiber fabrication using an initial “sacrificial” core.
- Validated alternating current impedance (ACI) spectroscopy technique for measuring membrane proton conductivity, and deployed technique in assessing two NDSU-fabricated PIC membrane samples. The membranes—which comprised heat-pressed matted core–shell nanofibers—were found to have proton conductivities of about 0.2 × 10-3 S/cm at 300°C and varying steam levels.
- Improved method for synthesis of ruthenium and ruthenium oxide on reduced graphene oxide (Ru–RuO2/RGO) catalyst. The method enables preparation of catalyst with smaller and more highly dispersed Ru and RuO2 nanoparticles than achievable with the previous method.

More details are available in the full report.

July 2019
Status report received. The accomplishments achieved in the time period of April through June include the following:

- Devised, fabricated, and tested an alternative PIC membrane configuration—referred to as Membrane Configuration 4 (MC4)—comprising an IPC disk infiltrated with PBI.
- Partially completed fourth milestone (Milestone 3.3)—fabricate PIC membrane with proton conductivity ≥0.5×10-2 S/cm and gas permeability <10% at 300°C—as described in Progress and Status (Task 3).
- Developed an alternative protocol for cathode catalyst screening, as described in Progress and Status (Task 4). Implementation of the protocol is contingent on DOE approval.

More details are available in the full report.

Updated 8/2/2019