June 1, 2009

Ms. Karlene Fine
Executive Director
Renewable Energy Development Program
North Dakota Industrial Commission
600 East Boulevard Avenue
State Capitol 10th Floor
Bismarck, ND 58505-0310

Dear Ms. Fine:

Subject: Project Status Report Entitled “Renewable Electrolytic Nitrogen Fertilizer Production”
          Contract No. R002-006; EERC Fund 9931

Enclosed is a hard copy of the subject project status report for the period of March 1 – May 31, 2009. If you have any questions, please contact me by phone at (701) 777-2982, by fax at (701) 777-5181, or by e-mail at taulich@undeerc.org.

Sincerely,

Ted R. Aulich
Senior Research Manager

TRA/cs

Enclosure
RENEWABLE ELECTROLYTIC NITROGEN FERTILIZER PRODUCTION

Project Status Report

(for the period of March 1 through May 31, 2009)

Prepared for:

Karlene Fine
Executive Director
Renewable Energy Development Program
North Dakota Industrial Commission
600 East Boulevard Avenue
State Capitol 10th Floor
Bismarck, ND 58505-0310

Contract No. R002-006

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RENEWABLE ELECTROLYTIC NITROGEN FERTILIZER PRODUCTION

PROJECT BACKGROUND

U.S. agriculture is dependent on nitrogen fertilizers, but the U.S. nitrogen fertilizer industry is at serious risk because of the high price of natural gas, the primary source of hydrogen for reaction with elemental nitrogen (N\textsubscript{2}) to yield ammonia. A fertilizer in its own right, ammonia is also the feedstock for production of urea, ammonium nitrate, and other nitrogen fertilizers. The high cost of natural gas, which accounts for at least 80% of the cost of ammonia—and by extension, the cost of all other nitrogen-based fertilizers—has resulted in a significant increase in fertilizer imports and a significant reduction in U.S. fertilizer production capacity. Ten years ago, the U.S. imported 35% of its fertilizer consumption, while in 2005, imports accounted for almost 80%. To ensure against overdependence on imported fertilizer, it is of urgent importance to develop domestic ammonia production capabilities that can compete with current import-based scenarios that include the use of low-cost “stranded” natural gas; large-scale ammonia production via the high-pressure, high-temperature Haber–Bosch process; and long-range ammonia and ammonia-based fertilizer transportation to U.S. farmers.

PROJECT DESCRIPTION

The University of North Dakota Energy and Environmental Research Center (EERC) recently developed an electrolytic ammonia production process that replaces high-cost, high-purity natural gas-derived hydrogen with lower-cost biomass gasification-derived syngas (bio-syngas). Because it is driven by electricity and operates at significantly lower temperature and pressure than the Haber–Bosch process, the EERC process offers the potential to directly utilize wind-generated electricity for production of fertilizer at significantly reduced capital and operating costs versus the Haber–Bosch process. Commercialization of the EERC process would 1) result in lower-cost fertilizer, 2) help the domestic fertilizer industry survive by eliminating the need to buy natural gas, 3) enable extracting value from wind energy without the need for major expansion of expensive, difficult-to-permit transmission capacity, and 4) promote rural economic development on the wind-rich Great Plains. The EERC process offers the potential to compete economically with imported fertilizers and simultaneously develop a new fertilizer production industry that is based on smaller-scale, widely distributed production. Figure 1 is an overview of how the process would be implemented on a commercial scale.

The EERC renewable ammonia process operates at a reaction temperature of 200°C–400°C with inputs of bio-syngas, air-extracted nitrogen, and electricity. Figure 2 illustrates electrolytic ammonia production using a proton-conducting electrolyte membrane. A humidified mixture of hydrogen (H\textsubscript{2}) and carbon monoxide (CO) is fed to the porous anode layer and is simultaneously oxidized at the anode–electrolyte interface, resulting in formation of protons. The protons transport through the proton-conducting electrolyte layer under applied voltage and reach the cathode–electrolyte interface where N\textsubscript{2} is electrolytically hydrogenated to yield ammonia (NH\textsubscript{3}). Because of the direct use of syngas rather than high-purity hydrogen, process complexity and cost are significantly reduced versus the Haber–Bosch process.
The EERC—in partnership with the North Dakota Renewable Energy Council, North Dakota Corn Utilization Council, and Minnesota Corn Research and Promotion Council—is engaged in a 1-year project to optimize the EERC renewable electrolytic ammonia production process as a prerequisite for process commercialization. The primary project objectives are to 1) optimize the ammonia production process using a single 2-watt (2-W) electrolytic cell and
2) Optimize the process using a 200-W multicell “stack,” using the resulting data and information to design a 50- to 200-kilowatt (kW) stack capable of integration with a biomass gasification system to enable demonstration of a complete biomass-to-ammonia process. Progress made on Tasks 1 and 2 is described below.

**Progress on Task 1 – Process Optimization in a Single 2-W Electrolysis Cell**

Task 1 process optimization activities are being conducted using an EERC-designed and fabricated 2-W planar electrolyzer with two gas chambers (an anode chamber and a cathode chamber) separated by a membrane electrode assembly (MEA). During the March 1 – May 31, 2009, reporting period, Task 1 activities continued to focus on optimization of the cathode catalyst for promoting the ammonia production reaction of:

\[
N_2 + 6H^+ + 6e^- \rightarrow 2NH_3
\]

As reported previously, cathode catalyst screening activities led to development of a catalyst with the desired high activity for ammonia formation and high overpotential for hydrogen evolution. The catalyst has been significantly improved. The compositional ratio of the key metallic components of the catalyst and the temperature, pressure, and other parameters utilized in the catalyst fabrication process were optimized. As a result, cathode catalyst activity was improved to 60 millimoles of ammonia produced per hour per gram of catalyst (mmol hr\(^{-1}\) g\(^{-1}\)) at 350°C and atmospheric pressure, compared to the 15-mmol hr\(^{-1}\) g\(^{-1}\) activity reported in the previous quarter. To the best of our knowledge, this activity level is a record not previously seen in the literature; however, we believe further improvement is achievable. Research is now focused on maintaining high activity at lower temperature—ideally, a temperature of 200°–250°C—since this temperature range enables use of a wider choice of commercial membrane materials, which would help reduce the capital cost of the electrochemical cell. A catalyst has been developed with a measured activity of 10 mmol hr\(^{-1}\) g\(^{-1}\) at 250°C. This catalyst has undergone endurance testing for over 1 month and shown no sign of a decrease in activity.

**Task 2 – Process Optimization in a 200-W Multicell Stack**

Fabrication of the 200-W electrolysis system is ongoing. It is anticipated that system fabrication will be completed during the first half of the June–August quarter.