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Improved Energy Source for NDI Equipment Tools

Summary Report, Year 1

Reporting Period: May 25, 2016 to May 24, 2017

Contract No. FA8100-16-C-0002

Submitted by:

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Executive Summary

In this Phase II project, pH Matter and its partners will build a 25 W prototype fuel cell power system, and demonstrate operation of NDI equipment with the system. The project is on schedule except for demonstration of the 15-cell stack with developmental membranes, which should be completed within one month of the original milestone. In the report that follows, we review work completed during the first year of the project. pH Matter has incorporated experimental membranes and ionomer delivered from Bettergy and demonstrated excellent performance and stability at target air flows using up to 5 molar ethanol fuel. Further, the company demonstrated a 3-cell stack with external manifold that reduced pressure drop to an acceptable level for the COTS blower options. Lockheed has built and demonstrated a breadboard balance of plant and controls, which will eventually be integrated with the direct ethanol fuel cell stack. The stack and system design was presented to the Air Force project monitor in a design review meeting. Risks to project success that are immediately being addressed are sealing large area cells using developmental membranes (due to membrane expansion in the fuel), and reducing prototype system size which is inflated from the current stack compression design (both being addressed in pH Matter's ongoing work).

Research and Development (R&D) Project Work Plan

A Gantt Chart with the proposed project schedule and key milestones is shown below in Exhibit 1. The Summary Report for the first year is the contract deliverable for invoicing in the fourth quarter.

Table 1. Project work plan task timing and milestone Gantt Chart.

Tasks and Milestones/Deliverables	Quarter after Project Initiation							
	1	2	3	4	5	6	7	8
Task 1. Stack Development (pHM)	—	—	—	—				
⇒ 3-cell stack demonstrated		★						
⇒ 15-cell stack demonstrated				★				
Task 2. Membrane Development (Bettergy)	—	—	—	—	—	—		
⇒ Delivery of initial membranes	★							
⇒ Membranes with 10X less crossover			★					
Task 3. Design & Integration (pHM / LM)	—	—	—	—	—	—	—	—
⇒ Breadboard electronics demonstrated		★						
⇒ Initial prototype design complete				★				
⇒ Prototype system complete						★		
Task 4. System Testing (pHM / LM)					—	—	—	—
⇒ Breadboard system tests reported					★			
⇒ Integrated prototype system tests reported							★	
⇒ Environmental testing complete								★
⇒ 25W Prototype delivered to Air Force								★
Task 5. Management and Reporting (pHM)	—	—	—	—	—	—	—	—
⇒ Formal Meetings	★			★				★
⇒ Quarterly Engineering Progress Reports and Final Reports	★	★	★	★	★	★	★	★

Milestone/Task Status***Overview***

A Gantt Chart showing the project work plan tasks, timing, and key milestones was shown above in Table 1. Four tasks were worked on during the first year of the project. All tasks are on schedule, as elaborated below, with the exception of the initial 15-cell stack demonstration:

- **Task 1 Stack Development:** Within this task pH Matter improved cell performance and long-term stability. Key issues addressed in the first year of work included improving anode catalyst adhesion, and pressure drop across both sides of the cell. Further, an external-manifold cell stack was designed, built, and tested; target performance was demonstrated with the external air manifold approach. An unplanned sub-task was optimization of the cathode for operation with new developmental membranes. Target performance was achieved using the low-crossover membranes. Cell performance was also demonstrated in a 3-cell stack. The final major milestone of the task is demonstration of a 15-cell stack. One 15-cell stack was tested using commercial membranes, and demonstrated expected pressure drops and initial voltage. Long-term testing was limited due to ethanol crossover issues with the membranes. A second 15-cell stack will be tested using low-crossover developmental membranes within the next month, slightly behind the original milestones for demonstrating 15-cell stack performance.
- **Task 2 Membrane Development:** Bettergy developed and delivered experimental membranes with 10X lower ethanol crossover, achieving the month 9 milestone. Additionally, Bettergy delivered ionomer to pH Matter. The new membranes were tested at pH Matter and demonstrated that at least 5 M ethanol concentration operation can be achieved. Bettergy will continue to deliver membranes and ionomer to support stack testing.
- **Task 3 Design and Integration:** Lockheed completed initial testing of the breadboard voltage regulation and controls electronics. This demonstration of the equipment with a power supply, load box, and balance of plant met the major task milestone for year 1. The design of the packaged electronics for the initial prototype, was completed for the preliminary design review.
- **Task 5 Management and Reporting:** This report is being submitted as the milestone/deliverable for invoicing at the end of quarter 4 / year 1.

Projected Performance

The key projected performance features of the production alcohol fuel cell system have not deviated from the performance projected in the proposal. The current prototype deliverable for this project was presented in the design review; this design is expected to change over the next three months as the system is more refined for integration with the Olymou-Nortec 600 series of equipment.

Table 2. Comparison of non-proprietary proposed prototype feature values and current projected end-product performance values.

End Product Feature	Proposed Design Targets	Projected Production Value	Current Projected Prototype
Power	25 Watts (Average)	25 Watts (Average)	25 Watts (Average)
Size	Fits on back of NDI	< 1 L	See Design Review
Dry Weight	< 1 kg	<1 kg	See Design Review
Fuel Source	Denatured Ethanol	Denatured Ethanol	Denatured Ethanol

Accomplishments

The details of the key results for individual tasks are included in the proprietary versions of the quarterly reports. Key major accomplishments of the first year of work included:

- Bettergy's development of a membrane that prevents ethanol cross-over and enables long-term operation in at least 5 M ethanol.
- Demonstration of a direct ethanol fuel cell for over 100 hours (when the test was stopped) using up to 5 M ethanol. To the best of our knowledge, this has never been demonstrated in any published data.
- Design, development and demonstration of an external air manifold for the stack.
- Anode and cathode performance and pressure drop optimization.
- Demonstration of a 3-cell stack.
- Design of controls and integration of a breadboard circuit.
- Design of a 25-Watt prototype system.
- Build of a full-sized 15-cell stack.

Key Dates

A 15-cell stack test incorporating developmental membranes and demonstrating target performance will be completed by the end of the next month (June 30th).

Designs

The initial prototype design was presented to the project monitor in a design review meeting at the end of year 1. Based on feedback received during that meeting, several features of the design will be modified. Specifically, the design will be optimized for operation with Nortec 600 equipment. The prototype design will be completed by the end of 16th month of the project (September 25th) to enable construction of the enclosed prototype system by the end of the 18th month (November 25th).

Outstanding Problems

Previously, we reported cathode flooding as the primary challenge. These issues were addressed with further membrane modifications in single cell tests. Excellent results were obtained this quarter with Bettergy's fourth generation membrane. Stability at the stack level with the improved membrane formulation will be demonstrated next month, pending the solution to the new edge leaking problem discussed below.

New Problems

Edge leaking. The fourth generation membranes have solved crossover problems, but expansion of the membranes has led to leaks on the edge of the seals. This is particularly a problem in full-sized cells and stacks. The issue is being addressed by modifying the stack building procedure.

Prototype Size. The prototype system design is currently larger and heavier than desired because of the need for external compression of the cell stack. This external compression is necessary for the experimental prototype to allow the components to be re-usable. Further system design refinements will be made over the next 3 months to reduce the prototype size and make it more attractive for demonstration purposes.

Significant Results (presentation and publications)

An abstract has been submitted for presentation of work on this project at the 2017 Fuel Cell Seminar this November in Long Beach, CA.

Other Information

pH Matter is moving to a new facility starting June 1st. The new address will be:

6655 Singletree Dr.
Columbus, OH 43219

The move is not expected to impact the project significantly. There is no other information to report regarding issues which may cause significant changes in the program schedule.

Future Plans

Work planned for the next quarter of the project includes:

- Task 1 Stack Development: pH Matter will demonstrate performance targets in a 15-cell stack with Bettergy Fourth Generation membranes.
- Task 2 Membrane Development: Bettergy will continue membrane and ionomer fabrication to support stack and system development.
- Task 3 Design and Integration: Lockheed will modify the controls design based on any prototype system design changes and continue test the modified breadboard control electronics with a power supply (to simulate the stack) and load box (to simulate NDI equipment). The breadboard electronics will be delivered by the end of the quarter to pH Matter for testing with a stack.
- Task 5 Management and Reporting: A quarterly report will be submitted as the milestone/deliverable for invoicing at the end of quarter 5.

Itemized Man-hours and Costs

A summary of itemized labor-hours, and contract expenditures are as follows:

Total Project: \$746,509.31

Paul Matter, PI: 482 man hours, Chris Holt, Sr. Scientist: 205 man hours, Michael Beachy, Sr. Engineer: 684 man hours, Minette Ocampo, Chemist: 317 man hours, Technicians/Interns: 1,168 man hours. Total salary expended through the first year was \$89,422.00. Indirect and fringe expenses were \$52,311.87 and \$26,826.60, respectively. Supplies and equipment expenses were \$11,473 and \$16,063, respectively. The Bettergy and Lockheed Martin sub-awards and third-party machine shop costs for the first, second, and third quarter were \$113,505. pH Matter charged a profit of 6.85%, for a total of \$21,207.70. The total expenditures for quarters 1, 2, 3, and 4 totaled \$330,809.17. There are \$415,700.14 funds remaining on the project as of this reporting date.

Deliverable Status

The status of deliverables, including item and contract identification, shipping/transmittal ID, status, security classification, and schedule due date information are given below:

Item	CDRL	Shipping ID	Status	Security Classification	Due Date
Kick-off Presentation	004	0001AA	Accepted	Distribution B	6/25/16
Interim Report #1	001	0001AB	Accepted	Distribution A	9/25/16
Interim Report #2	001	0001AC	Accepted	Distribution A	11/25/16
Interim Report #3	001	0001AD	Accepted	Distribution A	2/25/17
Summary Report #1	002	0001AJ	Current	Distribution A	5/25/17
Interim Report #4	001	0001AF		Distribution A	8/25/17
Interim Report #5	001	0001AG		Distribution A	11/25/17
Interim Report #6	001	0001AH		Distribution A	2/25/18
Summary Report #2	002	0001AJ		Distribution A	6/25/18
Final Report	003	0001AJ		Distribution B	6/25/18

Report Preparer

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