VI.2 Reduction in Fabrication Costs of Gas Diffusion Layers

Jason Morgan
Ballard Material Products (BMP)
2 Industrial Ave.
Lowell, MA 01851
Phone: (978) 452-8961 x5213
Email: Jason.Morgan@Ballard.com

DOE Managers
HQ: Nancy Garland
Phone: (202) 586-5673
E-mail: Nancy.Garland@ee.doe.gov
GO: Jesse Adams
Phone: (720) 356-1421
E-mail: Jesse.Adams@go.doe.gov

Contract Number: DE-FG36-08GO18051/A000

Subcontractors:
- The Pennsylvania State University, University Park, PA
- Ballard Power Systems (BPS), Burnaby, BC

Project Start Date: October 1, 2008
Project End Date: August 31, 2011

Fiscal Year (FY) 2011 Objectives

- Reduce the fabrication costs of gas diffusion layer (GDL) products by:
  - Reducing the number of process steps.
  - Replacing batch processes with continuous processes.
  - Utilizing in-line measurement tools to reduce costly ex situ testing.
- Develop and implement new, high volume GDL process technologies.
- Produce high-performance, low-cost GDLs at sufficient volumes for near-term fuel cell markets.
- Research, develop, and implement new in-line process control and measurement tools consistent with high volume manufacturing.
- Advance the understanding of the relationship between process parameters, ex situ GDL properties and fuel cell performance to maximize production of high-performance, low-cost GDLs for near-term markets.

Technical Barriers

This project addresses the following technical barriers from the Manufacturing R&D section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Lack of High-Volume Membrane Electrode Assembly Processes
(F) Low Levels of Quality Control and Inflexible Processes

Contribution to Achievement of Manufacturing R&D Milestones

This project will contribute to achievement of the following DOE milestones from the Manufacturing R&D section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1: Develop prototype sensors for quality control of MEA manufacturing. (4Q, 2011)
- Milestone 2: Develop continuous in-line measurement for MEA fabrication. (4Q, 2012)
- Milestone 3: Demonstrate sensors in pilot scale applications for manufacturing MEAs. (4Q, 2013)
- Milestone 4: Establish models to predict the effect of manufacturing variations on MEA performance. (4Q, 2013)

FY 2011 Accomplishments

- Reduced GDL costs by 55% from $36/kW to $16/kW from FY 2008 to FY 2010 by:
  - Increasing the manufactured width from 40 cm to 80 cm wide.
  - Implementing process control tools to improve product uniformity, reducing the amount of ex situ testing, improving product yields and minimizing scrap rates.
  - Installing new equipment enabling the production of rolls over 800 m in length.
  - Developing empirical models to predict and control critical GDL properties early in the manufacturing process, thereby improving manufacturing efficiency.
- Manufactured multiple batches of various types of microporous layer (MPL) inks (10^+ gallons per batch) using a 2” continuous mixer.
  - Purchased a rheometer to measure the visco-elastic properties of these various MPL inks:
    - Developed test methods to characterize our inks.
    - Collected data on both our standard and continuous inks.
    - Began to determine relationships between continuous mixing parameters and key fluid properties.

  - Established mixing procedures to reduce the amount of agglomerations formed during the continuous mixing process.
  - Successfully developed a process to filter and de-gas the continuous MPL inks.
- Manufactured rolls of GDL material combining the many-at-a-time (MAAT) coating process with continuously made inks:
  - Produced multiple rolls (~80 m) of both anode and cathode material within production specifications with minimal defects.
  - Verified fuel cell performance in both a single-cell and a 10-cell short-stack.
  - Optimized dryer profile utilizing non-contact infrared thermocouples throughout the oven and dew point sensors to prevent premature drying of top layer.
  - Due to modifications to the MPL ink formulations, the coating head slot heights were altered to eliminate coating defects and improve basis weight uniformity.
  - Improved GDL uniformity by installing mass flow meters for each MPL ink and continuously monitoring basis weight with an in-line basis weight tool.
- Identified, purchased and installed new process control tools for multilayer coating, in-line mixing and heat treatment processes:
  - Mass flow meters (in-line mixing/MAAT coating).
  - In-line basis weight tool.
  - In-line viscometers.
  - Non-contact thermocouples for MAAT drying conditions.
  - Non-contact thermocouples for heat treatment process (high temperature).
- Developed a method to relate continuous on-line Raman scanning, to slow off-line area Raman scanning in an effort to:
  - Investigate a link between poly-tetrafluoroethylene (PTFE) distribution throughout the GDL and GDL drying conditions.
  - Demonstrate that on-line Raman scanning will detect the differences at required speeds for an on-line manufacturing tool.
  - Determine if differences in PTFE distribution throughout the GDL have an impact on critical ex situ properties of GDL and/or in situ fuel cell performance.
- Examined each step of the manufacturing process and determined relationships between specific process parameters and critical GDL properties.
  - Developed empirical models to predict and control critical GDL properties early in the manufacturing process.
  - Implemented methods to adjust the manufacturing process to center GDL properties within production specifications to ensure proper functionality.
- Improved manufacturing capacity 4-fold from FY 2008 to FY 2010.
  - Additional capacity increases are expected to reach ~9-fold with the full implementation of continuous mixing and multilayer coating technologies demonstrated in this project (requires additional capital investment to complete).

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Introduction

This project addresses the Manufacturing R&D sub-program's goal of research, development and demonstration of technologies and processes that reduce the manufacturing cost of proton exchange membrane fuel cell systems. Specifically, this project reduces the fabrication costs of high-performance GDL products, while also increasing manufacturing capacity and improving product uniformity. The end result of this project is the production of low-cost, high-performance GDLs for near-term fuel cell markets, such as back-up power or materials handling. A conceptual design of a Greenfield manufacturing plant that is capable of meeting the 2015 GDL target price of $4/kW at specified volumes will also be developed.

Approach

The largest barrier to the commercialization of fuel cell products is cost. The cost of the GDL was evaluated at the end of 2008 and found to be $36/kW, almost 10 times the DOE cost target for 2015. A breakdown of this cost revealed that the majority of the fabrication cost of GDLs was due to manufacturing labor, specifically for ink mixing, coating and quality control.

It was believed that much of that cost could be removed by reducing the number of process steps, replacing slow batch processes with faster continuous processes, and utilizing modern on-line tools to improve product quality and reduce the amount of ex situ testing. In addition to these process modifications, it was also critical to determine the relationships between manufacturing parameters and critical GDL properties. From this understanding, empirical models will improve production controls, ensure product performance, and aid in the development of next generation GDLs that can meet the needs of state-of-the-art membranes and catalysts. Although the costs cannot be reduced to the DOE program target through this project alone, Ballard will use the knowledge gained in this project to design a Greenfield facility that is capable of producing

GDLs at or below $4/kW which should help meet the DOE stack target cost of $30/kW in 2015 at appropriate manufacturing volumes.

Results

Throughout this project, BMP has been able to reduce the fabrication costs of GDLs by 55% from $36/kW to $16/kW, as shown in Figure 1. This has been accomplished by increasing the manufactured width of the GDL from 40 cm to 80 cm, installing new web-handling equipment to allow for processing of rolls in excess of 800 m long, implementing better process controls, and incorporating an empirical process model which has resulted in improved process yields and reduced scrap rates. As a result of these efforts, the plant capacity has been increased 4-fold, as shown in Figure 2, which allows for production of low-cost, high-performance GDLs at volumes suitable for near-term markets.

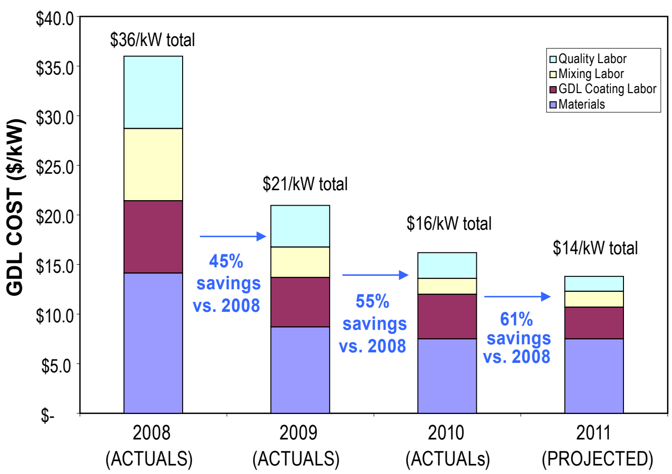


FIGURE 1. GDL Cost Reduction Data

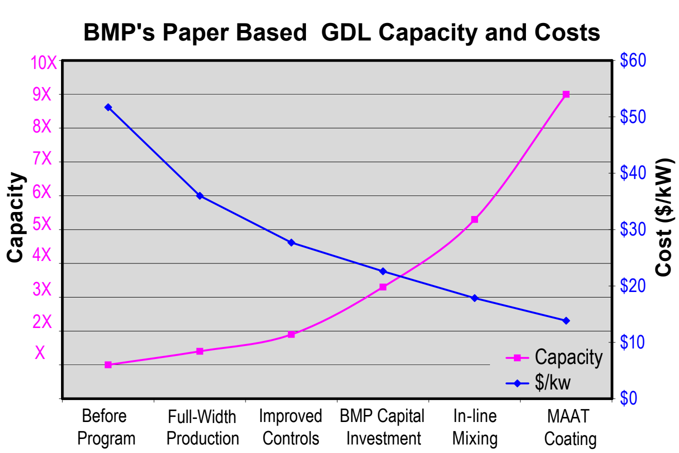


FIGURE 2. Impact of Various Program Milestones on Manufacturing Capacity and GDL Cost

Ballard has also demonstrated methods for future cost reductions based on the implementation of MAAT coating and continuous mixing. Multiple short rolls (~80 m) of anode and cathode GDL designs have been manufactured to date, demonstrating that GDLs manufactured with this new technology are similar to standard baseline materials [1]. Ex situ validation of GDLs made with these methods is shown in Figure 3, while in situ validations are still being completed and will be available in the next quarterly report. This validation work is different than previously reported work because it combines both MAAT coating and continuous mixing technologies together for the ultimate low-cost GDL design. Additional capital investments will be required by Ballard to fully integrate these new technologies into the GDL manufacturing process, but this work is critical in demonstrating their viability for GDL production.

In addition to the cost reduction work, Ballard has determined relationships between critical GDL properties and fuel cell durability and performance. Additionally, BMP has examined every step in their manufacturing process to find relationships between manufacturing process variables and these critical GDL properties [1]. These relationships have led to the development of empirical models, which allow BMP to predict and control critical GDL properties early in the manufacturing process. This understanding also allows BMP to make adjustments during the manufacturing process to meet specific customer targets, allowing for a more stable, consistent product, that improves yield rates and cell performance. This knowledge will also allow for the development of enhanced GDL designs that are tailored for a specific application (e.g. air-cooled vs. liquid-cooled) and should help in manufacturing GDLs with tight specifications.

The Pennsylvania State University, under the direction of Dr. Michael Hickner, is working with BMP to develop an in-line method for measuring the chemical homogeneity of the GDL. This work has led to the discovery of a potential link between PTFE distribution and GDL drying conditions,

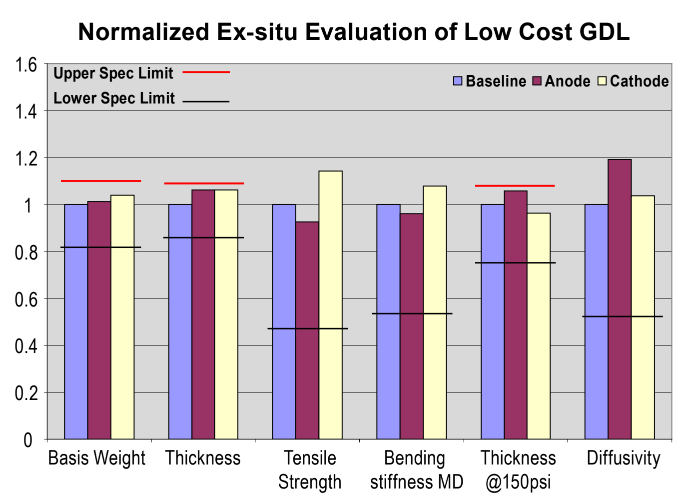
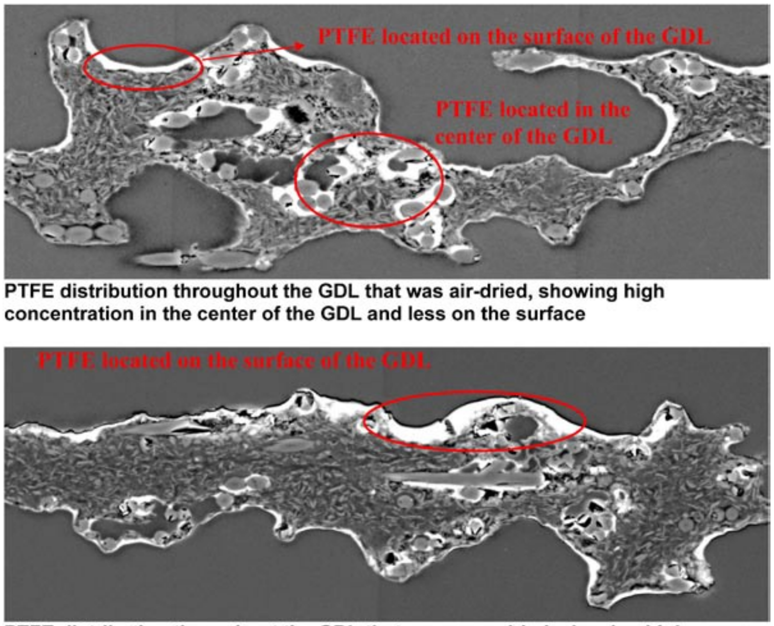


FIGURE 3. Ex Situ Evaluation of Low-Cost Anode and Cathode GDL Materials



PTFE distribution throughout the GDL that was air-dried, showing high concentration in the center of the GDL and less on the surface

PTFE distribution throughout the GDL that was oven-dried, showing high concentration on the surface and minimal concentration in the center

FIGURE 4. Impact of Drying Conditions on PTFE Distribution throughout the GDL

as shown in Figure 4. Dr. Hickner's team has demonstrated that on-line Raman scanning can detect differences in the PTFE distribution at speeds high enough to be used as an on-line manufacturing tool. In an effort to further this understanding, BMP has manufactured a variety of GDL designs with different PTFE loadings that were exposed to various drying profiles. Dr. Hickner's team is now working on determining if differences in PTFE distribution throughout the GDL are seen in these samples, while BMP and BPS are working to determine if there is a significant impact on critical ex situ properties of GDL and/or in situ fuel cell performance. This work will be valuable to the fuel cell community as a whole, by either providing a method to determine the PTFE distribution throughout the GDL with an on-line tool or demonstrating that variations in the PTFE distribution do not impact critical GDL properties or fuel cell performance.

Conclusions and Future Directions

BMP was able to reduce the fabrication costs of GDLs by 55%, while increasing manufacturing capacity 4-fold and improving product quality throughout this project. Multilayer coating and in-line mixing technologies have been successfully combined and ex situ testing showed that both anode and cathode materials were within production specification, while in situ testing (both single cell and short stack testing) is underway to validate fuel cell performance. These technologies will lead to further cost reductions (~65% from FY 2008) and capacity increases (~4-fold from FY 2008) with appropriate capital investments by Ballard to bring them on-line. In addition, Ballard has been able to determine relationships between critical GDL properties and fuel cell performance/durability. BMP has determined relationships between various manufacturing parameters and these critical GDL properties, which will allow for more uniform GDL production, improved GDL design and increased production yields. This work is beneficial for production of high-performance, low-cost GDLs for near-term fuel cell markets, as well as the development of new GDLs to meet the needs of state-of-the-art membranes and catalysts.

The Pennsylvania State University, under the direction of Dr. Michael Hickner, has determined a method to measure PTFE distribution in the GDL using Raman Scanning at rates fast enough to be considered for use as an on-line tool. They are currently examining a variety of GDL designs with different PTFE loadings made with different drying profiles to determine if there are differences in PTFE distribution. This work, combined with ex situ GDL measurements and in situ cell performance data gathered by Ballard, is important to understand how variations in the PTFE distribution throughout the GDL influence fuel cell performance, if at all.

In the final months of this project the activities include:

- Production of commercial length rolls of both anode and cathode GDL designs using both continuously made inks and MAAT coating.
- Validation of these low-cost GDL materials utilizing ex situ validation as well as single-cell, short-stack and full-stack testing.
- Determination of manufacturing capability with these new process technologies with a goal of achieving 6 sigma standards.
- Completion of the design of a Greenfield facility capable of producing GDLs that meet the DOE 2015 target at specified volumes.
- Determination of the impact of PTFE distribution on both ex situ GDL properties and in situ fuel cell performance, as well as development of a measurement process that could be used as an on-line process control tool for GDL manufacturing.
- Pennsylvania State University will complete their work on Raman scanning and deliver a measurement procedure that is capable of being converted to an on-line process control tool with the appropriate capital investment.

Special Recognitions & Awards

1. 2011 DOE Hydrogen and Fuel Cell Program R&D Award.

FY 2011 Publications/Presentations

1. Mendoza A.J., Hickner M.A., Morgan J., Rutter K., and Legzdins C., "Raman Spectroscopic Mapping of the Carbon and PTFE Distribution in Gas Diffusion Layers", Fuel Cells, No. 2, 248-254, 2011.

2. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, Washington, DC, May 12, 2011.

References

1. Morgan, J, "Reduction of Fabrication Costs of Gas Diffusion Layers", DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting, Washington, DC, May 12, 2011.

Acknowledgements

I would like to acknowledge the technical leadership and contributions of Don Connors, Dan Nelson & Kathryn Rutter at Ballard Material Products, as well as Dr. Michael Hickner & Alfonso Mendoza at Pennsylvania State University and our colleagues at Ballard Power Systems in Burnaby, B.C.