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INTRODUCTION

The fuel cell industry is attempting to move beyond the *proof-of-concept* and *pilot production* phase and into a *production-ready* phase. This paper will highlight one example where the development teams of **Plug Power, Inc.** of Latham, NY and **Entegris, Inc.** of Chaska, MN crystallized requirements, nurtured product concepts, and integrated enabling technologies into a viable solution for the fuel cell industry.

PLUG POWER GenSys™ POWER GENERATION MODULE

As an industry leader in stationary, PEM-based fuel cell systems, Plug Power's commercialization strategy is to leverage their core innovation product (i.e., SU1) to establish strategic platforms (e.g., GenCore™, GenSys™), which can then be easily adapted to fit a variety of applications.

Figure 1: GenSys™ SU1 proof-of-concept 5kW stationary system

One critical component of the GenSys™ fuel cell system is the manifold assembly. The main function of the manifold assembly is to direct various fluids such as reformate, air, water, and coolant to and from the mechanical components in the power generation module, including the fuel cell stack, in order to produce the required thermal/electrical power. Fluid control is accomplished via valves, condensate drains, and other similar devices. Key issues that must be addressed in the design include:

- *Functional performance* – Flow rate, pressure drop, sealing, permeation resistance, etc.
- *Structural performance* – Stress, deflection, etc.
- *Compatibility with various fluids* – Hydrogen, coolants, etc.
- *Weight/volume*
- *Serviceability, reliability, etc.*
- *Costs* – Non-recurring, recurring

COLLABORATION BETWEEN PLUG POWER AND ENTEGRIS

As part of Plug Power's Extended Enterprise model, both Plug Power and Entegris realized that collaboration would be critical for success. The following techniques were used throughout the multi-phase manifold project:

- *Semi-weekly conference calls* – With entire cross-functional design team
- *Project management tools* – Project scheduling software, weekly meeting notes
- *Periodic face-to-face reviews* – Averaging two per month
- *On-site support* – Entegris designer on-site at Plug Power

- *Common engineering/analysis tools* ⇒ PTC-based FEA, CFD software

GENERATION I MANIFOLD ASSEMBLY

The first-generation manifold assembly used in the SU1 system consisted of a two-piece, polyetherimide (PEI) bonded assembly designed by Plug Power and produced by a third party supplier.

Figure 2: GenSys™ SU1 proof-of-concept 5kW stationary system manifold components

The main areas of concern for Plug Power were leaking due to stress cracks, uncertainty regarding material compatibility, and costs (including design, manufacturing, and testing.) Plug Power discussed potential improvements with Entegris. An incremental approach was chosen to lower risk and shorten implementation timelines.

GENERATION II MANIFOLD ASSEMBLY

While performance characteristics of candidate materials are fairly well known, Plug Power and Entegris agreed to embark on additional testing to characterize potential materials after exposure to dionized water and several other coolants. The following materials were selected for material compatibility testing to provide options along the entire performance and cost spectrum for plastics.

Class of Material	Performance	Cost
High-density polyethylene (HDPE)	Lower	Lower
Polyoxymethylene (POM)	Medium	Medium
Polyamide (PA)	Medium	Medium
Polyvinylidene Fluoride (PVDF)	Higher	Higher
Polyphenylene Sulfide (PPS)	Higher	Higher
Polyphenylsulfone (PPSU)	Higher	Higher

The material properties being evaluated included *weight change, width change, length change, thickness change, maximum stress change, tensile modulus change, and tensile strain change.* From the test results and Entegris' polymer materials expertise, the decision was made to use Polyvinylidene Fluoride (PVDF) for the manifold. The ensuing product concept was for a four-layer assembly in which the layers were machined from billet PVDF. Adhesive, bolts, and threaded fasteners were used to attach the four layers together. Manifold assemblies were produced and tested by Entegris. Plug Power received the completed manifold assemblies and successfully integrated them into their internal test program.

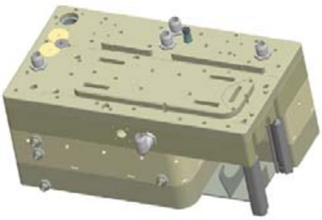

Figure 4: Generation II manifold assembly

GENERATION III MANIFOLD ASSEMBLY

With the experience gained from the Gen II phase, the teams agreed to separate the three key functions of the manifold assembly for Gen III: 1) *To transport fluids*; 2) *To store fluids* and; 3) *To support the mass of the power generation module components*. This led to the use of a steel frame structure to support a majority of the mass allowing the manifold to become less of a load-bearing component. In addition, the water tank was separated from the manifold. Since the tank was no longer supporting a significant mass, it was made by rotomolding high-density polyethylene (HDPE) into a lighter weight, lower cost solution.

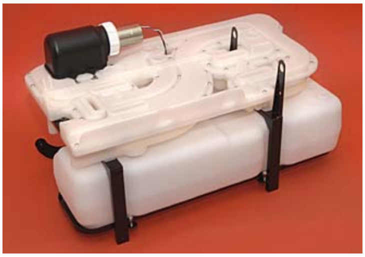

Figure 5: Generation III manifold assembly

With the experience of the Gen II manifold assembly the Plug Power/Entegris team decided to embark on a new venture, a fully integrated 3-way solenoid valve, for the reactant streams. This new 3-way reactant valve was incorporated into the design cycle of the Gen III manifold assembly. The 3-way reactant valve utilized many features found in semiconductor-grade valves including the use of all plastic wetted surfaces. The body of the valve was made of machined PVDF in order to match all of the performance aspects of the manifold assembly.

A Finite Element Analysis (FEA) was conducted in parallel with the design of the assembly.

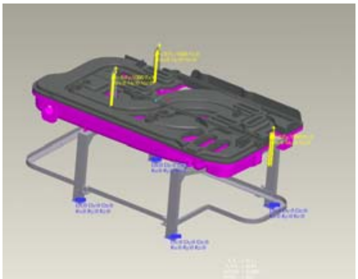

Figure 6: Finite element analysis of the manifold/frame structure

Displacements and maximum stresses were found to be within acceptable limits. No major modifications were made as a result of this static FEA.

Similar to the Gen II manifold assembly, the finished product was tested for leaks by submerging the manifold assembly into a tank of water and applying the maximum reactant pressures (with a factor of safety) to all different flow ports/channels. This test checks for both internal and external leakage. With no bubbles being visible over a specified period of time, the manifolds passed the acceptance criteria for leaking. Additional testing was also done at elevated temperatures. These manifold assemblies were subsequently shipped to Plug Power and have been successfully integrated into fuel cell systems.

Figure 6: Generation III manifold assembly undergoing leak testing at Entegris, Inc.

RESULTS AND DISCUSSION

The changes from the Gen II to Gen III manifold assembly produced a 50% reduction in parts, a 75% reduction in weight, and the cost to manufacture was reduced by 40%. Success in migrating from the Gen I version to the Gen III version included *clear top-level product requirements, a willingness by the fuel cell system developer to integrate different technologies and capabilities of the supplier, the ability to analyze the design and test the product early in the process, and a disciplined and collaborative approach to project management.* Projects like this are evidence that the industry, when working smartly and collaboratively, can move from a *proof-of-concept* and *pilot production* phase and into a *production-ready* phase.

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