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HYDROGEN PRODUCTION THROUGH ELECTROLYSIS

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Abstract

This paper describes the progress of cost reduction activities on a PEM electrolytic hydrogen generator series at Proton Energy Systems, Inc. (Proton) under cooperative agreement DE-FC36-98GO10341 with the Golden Field Office of the Department of Energy (DOE).

Proton's goal is to reduce the cost of our hydrogen generator family 50% by the end of 2002 and show evidence of further dramatic reductions in the years beyond. We will do this by focusing cost reduction efforts on three key elements of the electrolyzer: the electrolysis cell stack, the power conditioning and renewable interface, and the electrical controls and software. We will implement these reductions on our smaller (HOGEN® 40) electrolyzer first and expand those improvements to the larger electrolyzer towards the end of the program. All of the improvements undertaken on this program will benefit the full line of electrolyzers so that the cost of large and small energy storage applications will be reduced.

Proton has made significant progress in the last year on reducing the cost of many of the items in the hydrogen generator. As shown in Figure 1, cost reduction efforts are ahead of the schedule shown last year at the 2000 Annual Review. This is due to specific accomplishments on the program plus advances in other areas not covered in the program such as cost reductions in sheet metal and system assembly labor. It should be noted that all cost reduction projections from 2002 through 2005 are based on 500 units per year, and cost reduction projections beyond 2005 are based on 5000 units per year. These numbers are certainly not mass production numbers, but represent our projections of realistic numbers of units being sold into various markets. If one were to increase the numbers by a factor of ten or one hundred, then additional cost savings would certainly follow.

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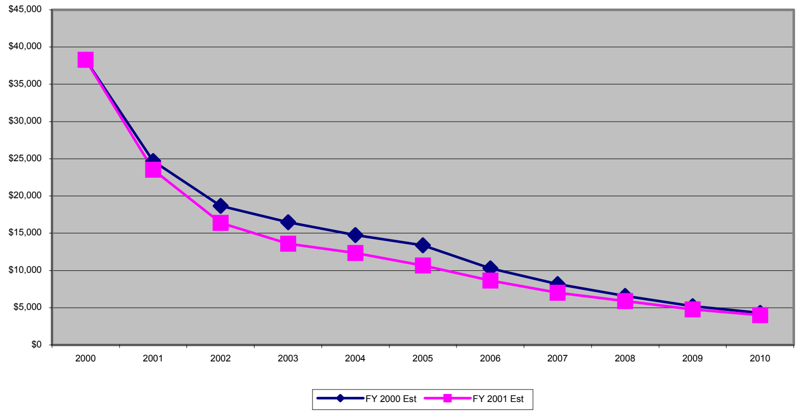

Figure 1 – HOGEN 40 (6kW) Ten Year Cost Projection

Background

Since the inception of the program on April 15, 1998, Proton has successfully demonstrated a fully functioning integrated renewable hydrogen utility system in conjunction with STM Power at Arizona Public Service (APS) in Tempe, AZ. This system coupled a solar concentrating dish, an external combustion engine and a Proton HOGEN®300 hydrogen generator. The system was installed and operating from May of 1999 through the end of the Phase I program in December of 1999. A description of the technical performance of the system and a market assessment is detailed in the Final Technical Report[1].

The Phase I demonstration efforts and market evaluation showed that a hydrogen generator coupled with some form of renewable power and some form of energy conversion device has a distinct advantage over a battery system backing up the same renewable application. Proton cannot determine which renewable technology will win out in the end, nor predict which energy conversion device will be the most cost effective. However, it is clear that the link to these alternatives lies in the ability to convert excess renewable power into hydrogen and have the hydrogen available for conversion back to power, on demand.

To that end, Proton proposed a Phase II that moved away from the solar concentrating dish effort and focused on cost reduction efforts aimed at the hydrogen generator family. The HOGEN® 40 was chosen as the model for these cost reduction efforts even though the HOGEN® 300 series generator was used in the Phase I of the program. This was done for two reasons. First, the smaller size of the HOGEN® 40 generator made cost reduction activities and hardware purchases less costly, and thus enable a larger scope of effort and impact on return. Second, advances are scalable. In other words, improvements and cost reductions made on the HOGEN® 40 can be scaled to the larger HOGEN® 300 series generators rather easily and with less financial and programmatic risk. The specifics of this proposal were outlined in the Technical Paper submitted for last year's annual review[2].

Long Term Goals

All of Proton's cost reduction goals are focused on the long term markets associated with sustainable power. However, there are three other markets where the hydrogen generator technology fits well and where products can move into commercial applications while the renewable technologies mature, come down in cost and become more commercially available.

These markets, shown in Figure 2, all have unique attributes that require different cost structures and pricing to compete effectively. Based on these markets and Proton's internal projections for numbers of units, market share and earnings, a detailed cost reduction plan was developed. The plan, as it pertains to hydrogen generators, focused on the HOGEN® 40 and the HOGEN® 380 sized units with the near term emphasis on the HOGEN® 40.

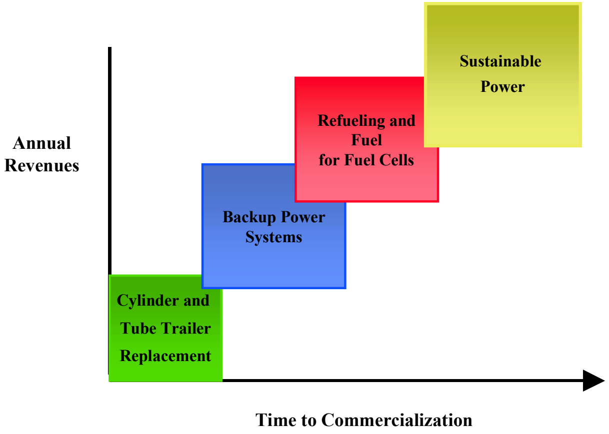

Figure 2 – Market Scope and Timing

The hydrogen program has a goal of hydrogen production at the lowest possible cost. To that end, Proton has established a cost goal of $1000 per kW in the near term and $500 per kW within ten years. The goal of $1000 per kW is achieved rather quickly on the larger generator, but requires a few more years on the HOGEN® 40. This is not unexpected, as the economies of scale on the larger unit are much more favorable than on the smaller unit. Regardless, both units project costs that are comfortably under $1000 per kW by 2010. The following sections will discuss in further detail the areas of cost reduction under the current agreement.

Technology and Product Impact of Program

The breadth of this program and the impact it has on the commercial rollout potential of PEM electrolysis is worth spending a little time discussing. All of the products and technology that Proton develops are born from PEM electrolysis. Advances in the core of that technology cross from one product to the next and impact all areas of our business. All of Proton's cost reduction goals are focused on the long term markets associated with sustainable power. However, there are other markets where the hydrogen generator technology fits well and where products can move into commercial applications while the renewable technologies mature, come down in cost and become more commercially available.

These markets all have unique attributes that require different cost structures and pricing to compete effectively. Based on these markets and Proton's internal projections for numbers of units, market share and earnings, a detailed cost reduction plan was developed. The plan, as it pertains to hydrogen generators, focused on the HOGEN® 40 and the HOGEN® 380 sized units with the near term emphasis on the HOGEN® 40. The cell stack sizes and system integration cost reduction tasks that are core to those products all transfer with minimal or no modifications to the other products.

When looking at the electrolysis cell stack, any changes to the cell materials of construction, the various catalyst loadings, or the stack embodiment, must be thoroughly tested to verify product integrity, safety and reliability. This type of testing can only be achieved through long duration testing of multiple configurations and designs. Regardless of the size of the cell itself, the improvements, or often more importantly the lessons learned, provide extremely valuable data and insight into possible cost reduction ideas. This program begins to move down that pathway with efforts targeted at catalyst loadings, materials substitution and improvements in manufacturing processing. These items have and will continue to be developed and put on test throughout this fiscal year up to the end of the program. Cost reduction projections assume at least one year of full testing before any changes are made on customer deliverable hardware. This conservative approach is vital to maintaining quality hardware and satisfied customers.

Often overlooked in the PEM fuel cell and electrolyzer product area is the importance of focus on system cost and integration issues. These areas encompass, at a minimum, fluids management, gas pressure, gas purity, manufacturability and all of the safety requirements in the various countries. Add to this the complexities in packaging and shipping hardware through different environments and over varying road infrastructures, and the pathway to delivering a fully commercial product gets even more complex. Proton has made significant advances in commercializing industrial hydrogen generators. This has included significant efforts in obtaining domestic and international marks such as CE, NTRL and CSA. This program has augmented these efforts by focusing on specific systems areas for cost reduction. These include the electronic control section, use of welded tube assemblies and exploration of various power conditioning options. As stated earlier, all of these cost reduction advances provide the building blocks for our other product areas and enable us to get real time commercial experience by applying these cost reductions to our industrial product lines.

Specific Accomplishments to Date

The following sections will discuss the specific areas targeted on this program, the milestones and objectives of each of those items and the status of progress to date.

Control Board Development

The current control system on the HOGEN® 40 generators has over 30 components, a significant amount of point to point wiring and discrete power modules. This task is aimed at integrating as many of these components as practicable into a dedicated control board. The task is a design effort, which utilizes a control board that was previously developed for our laboratory scale hydrogen generator (Figure 3) as a platform from which the functionality can be increased to encompass the necessary controls for the HOGEN® 40. An additional benefit of the board is the ability to utilize a digital operator interface and replace two analog gauges on the front panel (Figure 4.) This interface will allow for more detailed diagnostics and system monitoring by the operator/technician. The milestone for this item was to complete development testing of the prototype board by May of 2001. Prototype hardware testing is scheduled to conclude prior to May 31 with firmware testing to follow prior to June 15, 2001.

Figure 3– Current Control System

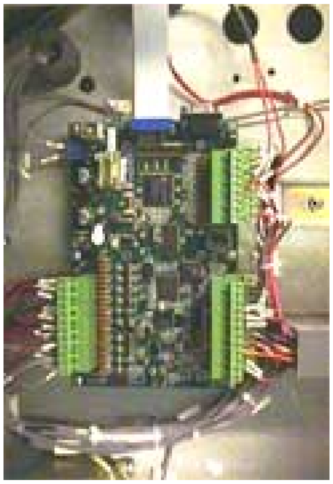

Figure 4 – Prototype Control Board

Efforts on the board have exceeded expectations. Testing has been very successful and has verified the hardware design and functionality. Some additional modifications and improvements are planned for the board beyond the prototype phase, which include integrating a few more components and reducing the overall production cost. The control board design, and associated validation testing, will be completed by the end of this calendar year. The cost reductions associated with this effort are impressive. The current material cost for the discreet components in the control system is approximately $1,600 and takes about 40 hours of labor to assemble. The board cost is projected to be approximately $300 and the labor will be reduced to less than one hour.

Power Supply

This task was intended to accomplish a full investigation of the landscape for power supplies that would be viable for the HOGEN® 40 series product. It was also intended to look for a universal interface that would be capable of taking input from various renewable sources.

The current design uses a switch mode power supply, which is very compact, power factor corrected, and efficient. However, the cost of the power supply is approximately $3,500 ($.35/watt) and the technology does not readily lend itself to cost reduction. Investigation of several alternatives led us to Sustainable Energy Technologies (SET) who developed a prototype

9kW power supply (Figure 5) that has a price of $1,500 ($.16/watt) at a quantity of 500 units. Our goal is to develop a power conditioning module that represents a technically equivalent alternative to the current power conditioning module at less than $.15/watt. The successful testing of the prototype unit provided by SET (Figure 6) has led us to believe that this is a goal well within reach.

Figure 5 – Prototype Power Conditioner

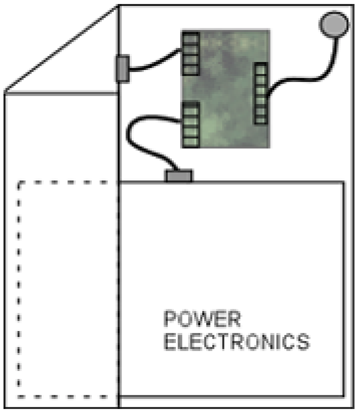

Figure 6 – Next Generation Concept

The only drawback to this prototype is the overall size, which is significantly larger than the envelope of the switch mode supplies. Further development activity will continue with SET to work on envelope versus cost. Another factor is that the success of the board activity has opened up potential volume in the current package that may be of adequate size to allow for a larger power supply. This analysis will continue throughout the remainder of this year.

Component Cost Reductions

The milestone on this task is to design and verify cost reductions on castings, manifolds, drying and fluid control components by September 2001. The idea is to take a significant look at fabrication methods, component count and technology being employed to reduce the overall cost of the fluid side of the system.

This item has shown very encouraging results. Reviewing fluid plumbing runs, simplifying them and replacing expensive tube fittings (Figure 7) with welded tubes (Figure 8) has reduced the overall fitting count by over 50%. This has had a major impact not only on the cost of the fittings and the assembly time associated with making up tube fittings, but the overall elimination of numerous leak paths has increased the robustness and integrity of the entire unit.

The development efforts on gas drying have enabled the development of a low cost pressure swing absorption dryer (Figure 9) that can be manufactured in low quantities for under $2,000 compared to the previous palladium membrane type of dryer being used for approximately $7,500. In higher volumes the cost of this dryer will be well under $1,000.

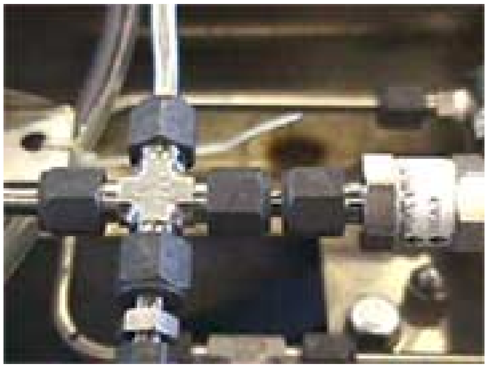

Figure 7 – Typical Fitting Connection

Figure 8 – Welded Tube Assemblies

Figure 9 – Pressure Swing Adsorption Dryer

Manufacture a Cost Reduced Prototype

The milestone for this task was to complete a prototype system to use as a test bed (Figure 10) for all of the cost reduction items by January 2001. The unit was completed in January and has been used for the testing of the control board as well as the development of the gas dryer and the new plumbing runs. It is our intention to build in all of the validated cost reduction ideas into this unit as a means of validating how they all relate and function as a system.

Figure 10 – Prototype System w/ Digital Interface

Alternate Energy Inputs

This milestone was designed as an investigation and understanding task. Numerous developers overlook, or fail to fully understand, the difficulty in interfacing different types of renewable technology with PEM products. As mentioned earlier in the Power Supply task, Proton has been working with SET to develop a universal interface. In addition, Proton has been working with Illinois Institute of Technology (IIT) on an overall system integration task combining a HOGEN® 40 (which they purchased), with a photovoltaic array and a fuel cell. This full-scale demonstration will provide valuable real world data on a complete system architecture. The renewable interface designed by SET will take a 5kW PV or Wind input with a wide input voltage range and utilizing full maximum power point tracking algorithms deliver a current controlled output to the electrolyzer for hydrogen production and storage. A HOGEN® 40 electrolyzer has been shipped to IIT and is scheduled to be fully functional on grid power by June 15, 2001. The SET renewable interface will be delivered to Proton on June 30, 2001 and following some initial testing will be shipped to IIT for integration and testing with a 2.6 kW PV system. Figure 11 below illustrates a typical renewable power system that might be utilized for small village or remote telecommunications applications. Demonstrations like IIT's help to make clear that the only long-term viable path to sustaining a renewable grid is through electrolysis and high-pressure hydrogen storage. The data and integration insight gained from this collaborative project will be invaluable to understanding the issues associated with designing, deploying, and maintaining renewable systems for a variety of applications.

Cell Stack

This milestone encompasses various tasks including catalyst loading reduction, process cost reduction for catalyst deposition and materials processing, design and analysis of cast stack components, and internal flow field material characterization. Completion dates are spread out through much of this calendar year. Due to the highly proprietary nature of these activities a full discussion of the specifics of this task will not be described in this paper.

In general, some of the detailed efforts are slightly behind schedule, but many significant advances are being made. Testing of many of these cost reductions are beginning and will require at least six months to one year of testing prior to being evaluated for possible implementation into a commercial product. Cost reduction assumptions have built in a two-year lag on improvement implementation.

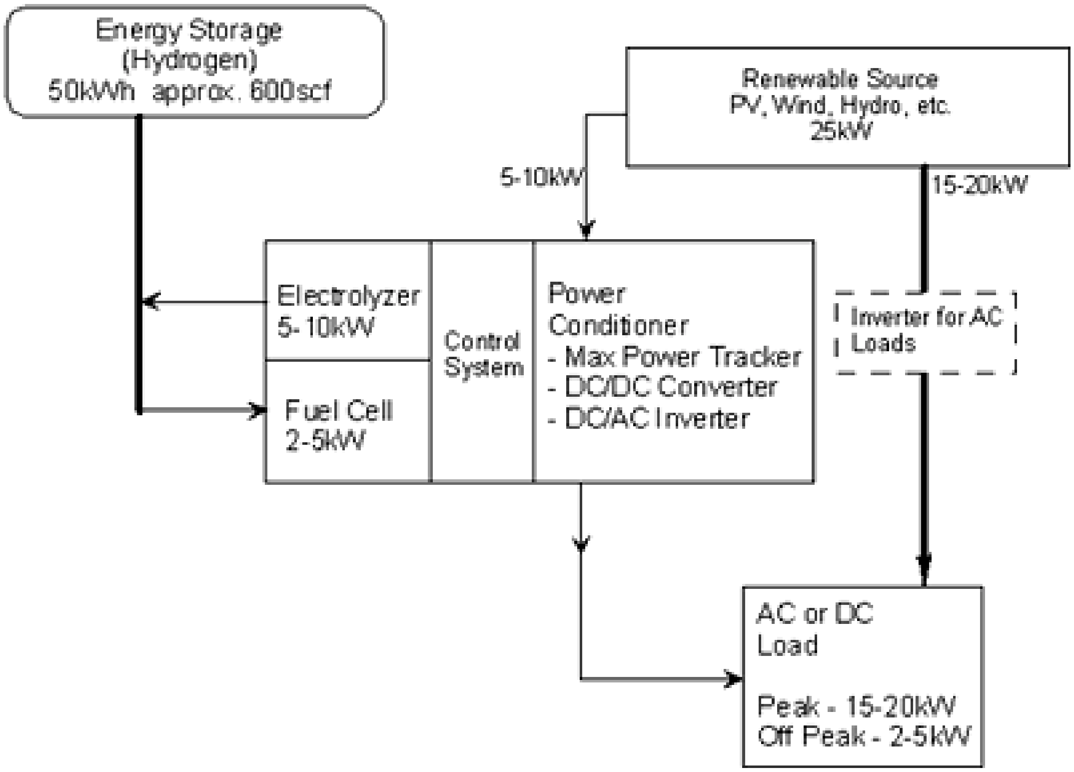

Figure 11 – Renewable Interface Concept

Plans for Future Work

The plans for future work revolve around completing work on the HOGEN® 40 efforts and beginning to advance them towards the HOGEN® 380 series generators. The first task is to fully validate and implement the cost reductions on the HOGEN® 40 product. Much of the verification testing is complete, but additional efforts remain on the control board to fully validate the design and implement production level cost reductions. The control board and some of the fluids components need to undergo further testing in order to achieve a confidence level high enough to integrate them into production. The second task is to continue testing and research on the cell stack efforts. Due to the time requirements of testing these items, the more advances we can make and get on test, the better our chances of achieving nearer term cost reductions.

Finally, on the HOGEN® 380 series generators, we will initiate design efforts on a control board based on the one designed for the HOGEN® 40. The essential functionality of the board is the same, but some of the on-board diagnostics and aspects of the system will differ to some extent. We will also look into power supply options on this unit. The various power supply options are somewhat different given the much higher power levels and larger package size.

References

1. Friedland, R., Smith, W., Speranza, A., January 2000. *Integrated Renewable Hydrogen Utility System*, Phase I Final Technical Report and Market Assessment PES-T-99014.

2. Friedland, R., May 2000. *Integrated Renewable Hydrogen Utility System*, Phase II Technical Paper for Annual Technical Peer Review.