II.B.2 Hydrogen Generation from Electrolysis, 100 kgH_2/day Trade Study

Stephen Porter
Proton Energy Systems
10 Technology Drive
Wallingford, CT 06492
Phone: (203) 678-2305; Fax: (203) 949-8016
E-mail: sporter@protonenergy.com

DOE Technology Development Manager:
Roxanne Garland
Phone: (202) 586-7260; Fax: (202) 586-2373
E-mail: Roxanne.Garland@ee.doe.gov

DOE Project Officer: Jill Sims
Phone: (303) 275-4961; Fax: (303) 275-4788
E-mail: Jill.Sims@go.doe.gov

Technical Advisor: Jamie Holladay
Phone: (202) 586-8804; Fax: (202) 586-2373
E-mail: Jamie.Holladay@ee.doe.gov

Contract Number: DE-FC36-04GO13030

Project Start Date: March 1, 2004
Project End Date: April 30, 2008

Objectives

- Establish pathway to larger proton exchange membrane (PEM) electrolyzers, 100 kgH_2/day and beyond.
- Optimize for capital cost and energy efficiency.
- Refine focus areas for future research.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production (3.1.4) section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency

Technical Targets

This project is developing a conceptual design of a PEM electrolyzer with decreased capital costs and increased efficiency, working towards the following 2012 Technical Targets:

TABLE 1. Progress Towards Meeting Technical Targets for Water Electrolysis

Characteristics	Units	100 kg/day Trade Study Kickoff	100 kg/day Trade Study Results	DOE 1,500 kg/day Target (2012)
Hydrogen Cost	(\$/kg)	\$7.86	\$5.21	\$3.70
Electrolyzer Capital Cost	(\$/kg) (\$/kW)	\$3.30 \$1,982	\$1.74 \$1,676	\$0.70 \$400
Electrolyzer Energy Efficiency	% (lower heating value)	42%	58%	69%

Accomplishments

- Significant gains against technical targets for cost and efficiency from initial scale-up analysis at kickoff to results of Trade Study.
- PEM systems in the range of 100 kgH_2/day are capable of meeting near term market commercial needs.
- New system topology identified that enables cost-effective solution to the divergent cell stack vs. power supply efficiency and cost optimization.
- Compact footprint achievable with only 3X increase in size for a 8X increase in generation capacity over current production systems.

✧ ✧ ✧ ✧ ✧

Introduction

Small-scale (100-500 kg/day) electrolysis is an important step in increasing the use of hydrogen as fuel. Until there is a large population of hydrogen-fueled vehicles, the smaller production systems will be the most cost-effective. Performing conceptual designs and analyses in this size range enables identification of issues and or opportunities for improvement in approach for larger systems, while maintaining robustness of cost estimates of components as they are not too far from what is produced today.

The objectives of this project are to establish the possible pathways to cost-effective larger PEM systems and to identify areas where future research and development efforts have the opportunity for the greatest impact in terms of capital cost reduction and efficiency improvements. A stepping stone approach to growing PEM electrolyzer systems in generation capacity will allow incremental lessons learned to be fully incorporated building on the positives while leaving any downsides behind on the path to 1,500 kg/day systems.

Approach

The approach to performing the research is divided into two main tasks. The first is to determine an optimum functional architecture by performing trade studies. The second is to bring together the results of the trade studies into a conceptual design of the system. The total steps taken are as follows:

- Optimize functional architecture
- Perform design trade studies
- Modeling and analysis using H2A
- Perform subsystem testing as appropriate for data
- Conceptual design/physical architecture
- Preliminary sizing of components
- Top level drawings
- Perform hazard analysis
- Obtain relevant budgetary quotations

The trade studies of the various subsystems examine potential implementations against one another in terms of performance and cost. Leading candidate subsystems are then combined and examined for performance and cost to check for interactions both positive and negative. The best solution for one subsystem as an example may place a burden on the next in line resulting in a less than optimal combination. Where data for the subsystem implementations was lacking some subscale testing was performed to gain insight into the relative performance.

The conceptual design leading to a physical architecture is performed by sizing of the components and generating a representative level computer-aided design (CAD) model. This along with the functional level documents such as a process flow diagram is then analyzed for hazards and mitigation techniques. Finally, quotations for the subsystems and other components such as the enclosure are obtained for future production quantities and timeframe so the H2A results are more accurate than escalation and learning curve prediction techniques.

Results

System Analysis using H2A Model

The H2A model was used for the system analysis to determine cost of the hydrogen produced. Details were added that allow changes in the cell stack architecture, such as membrane thickness based on current and future PEM designs. The modeling proved to be very useful in understanding how far certain aspects of the design need to be pushed beyond current capabilities to achieve the targets. This insight will help in getting the most value for the money spent on future research.

Key Trade Study, Cell Stack vs. Power Supply

The interaction of the cell stack size, active area and number of cells, vs. the operational parameters of the power supply that drives it was the key trade study in terms of overall cost and efficiency of the system. High output voltage and lower current is best for power supply efficiency and cost. A large active area with fewer cells, (resulting in lower voltage) is best for overall cost of the cell stack. A new topology for Proton which has one power supply driving multiple cell stacks in electrical series was determined to be the best middle ground solution.

Power Supply Trade Study

Two concepts for power supplies were selected to move forward: insulated gate bipolar transistor (IGBT) architecture as the primary, and semi conductor rectifier driven direct current (DC) motor drives as the fallback concept if unexpected problems with the IGBT are found. When incorporated in a system configured to meet our target price, the IGBT provides the highest overall efficiency. IGBT also provides the highest quality power with no additional equipment, and it is the most suitable to adaptation to receive DC input power from renewable energy sources.

IGBT technology-based power supplies are the preferred technology for conversion of wind power to the grid. It is likely that the costs will fall and the reliability and performance will improve for this technology power supply. The scale-up of the power supplies required for conversion of wind power going forward also complements the scale-up to much larger electrolysis systems.

Cell Stack Trade Study

Two cell stack architectures were examined as part of the trade study. One is a round plastic frame design which is the current production model. The second uses solid Ti bipolar plates, this has been experimented with. The results of the trade study comparing these two designs is that the bipolar plate design offers much greater efficiency as there are less interfaces but the solid Ti plates are expensive. Further study in composite type plates is warranted.

Conceptual Design

The main result of the conceptual design was a CAD layout of the system broken into four major compartments. The breakup of the compartments was driven by a hazard analysis as each section has its own types of hazards. An example is the cell stack power supplies. There is a significant arc flash hazard with an electrical feed approaching 300 kW. For the cell stacks, however there is the potential for leaks resulting in a combustible mixture hazard. Compartmentalizing the design into controls, power, hydrogen, and oxygen/water subsystems allows different mitigation techniques specific to the hazard to be used in a cost effective and safe manner.

Many of the subsystems sized for 100 kgH_2/day are essentially expansions of the current 12 kgH_2/day production system. Going to 500 kgH_2/day and larger will require significant changes in approach. For example, the phase separators may need to be large pressure vessels to handle the flows approaching 250 gpm. Also, with five times the power supply and cell stacks, the system will probably not be suited to building and shipping in a compact enclosure. The 500 kgH_2/day implementation will be more like installed plant equipment, or skids mounted in a container or small building.

Conclusions and Future Directions

This project is complete. Insights gained in the area of cell stack and power supplies for future research priorities are known. The cell stack capital cost requires reduction to approximately 25% of today's technology. The pathway to achieve this is through part count reduction, use of thinner membranes, and catalyst loading reduction. Capital cost reduction of the power supplies is achievable by modifying the system configuration to have the cell stacks in electrical series driving up the DC bus voltage allowing use of large-scale DC supply technologies. The single supply approach reduces cost.

The biggest opportunity for cost savings beyond that of the system examined is by increasing system efficiency to reduce electricity use. Some of the same improvements required to lower capital cost for the cell stack, parts count and thinner membranes, are also required to improve efficiency so a double benefit can be realized from future research in these areas.

Operating the cell stacks in electrical series allows high efficiency power supply topologies incorporating IGBT devices to be used. Electrical isolation of the balance-of-plant and water systems from the high DC bus voltages of these supplies requires further development. Maintaining high power conversion efficiency in light of the changing voltage of the cell stacks over their lifetime may require further study and possibly design enhancements to the internal controls of the power supply system.

FY 2008 Publications/Presentations

1. L. Moulthrop, M. Zoeller, E. Anderson, S. Porter, Commercial Progress, PEM-Based Hydrogen Generators For Fueling; *Proceedings of the NHA Annual Hydrogen Conference, Sacramento CA, 2008.*