IV.H.5 Alkaline, High-Pressure Electrolysis

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Subcontractors:
AeroVironment Corporation, Monrovia, CA
Pdc Machines Inc., Warminister, PA

Start Date: February 1, 2004
Projected End Date: January 31, 2007

Objectives

Develop and construct an alkaline hydrogen generator to meet the following objectives:

- Higher overall efficiency
- Low maintenance cost
- DFMA (Design for Manufacture and Assembly)
- Final output pressure of 5,000 psig

Technical Barriers

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

- G. Capital Costs
- H. System Efficiency
  - electrical efficiency of the electrolysis module
  - electrical efficiency of compressor
  - electrical efficiency of electrical conversion
- J. Renewable Integration
  - photovoltaic
  - wind
  - hydroelectric

Technical Targets

This project is conducting engineering studies and testing to achieve DOE H_2 production targets as described in Section 3.1.4 of DOE's Multi-Year Research, Development and Demonstration Plan. The specifics are summarized in Table 1.

The water electrolysis system under investigation is broken down into three critical components:

- electrolysis module
- power supply
- compressor

For each of the components, efforts are underway to improve efficiency and minimize production cost, utilizing benefits associated with production economies of scale.

Table 1. Summary of Specific 2005 DOE Targets Being Addressed by this Project

Segment	Cost (per gge H_2)	Efficiency
Power Conversion, Module, Balance of Plant	$0.80	68%
Compression, Storage & Dispensing	$ 0.77	94%
Electricity	$ 2.47	-
Operation & Maintenance (O&M)	$ 0.71	-
Total	$ 4.75	64%

Approach

- Perform trade studies and analyses to optimize system characteristics
- Design process and controls by utilizing benchtop systems
- Design the cell
- Design the module
- Fine tune design and controls
- DFMA (Design for Manufacture and Assembly)
- Fabricate deliverable system
- Test, debug and demonstrate deliverable system

Accomplishments

- Molded components for the electrolysis module have been procured. This allows consolidation of parts and cost reduction.
- Membrane fabrication hardware has been installed at the Teledyne Energy Systems Inc. (TESI) facility. Membrane samples have been successfully produced, and preliminary membrane testing in an electrolysis stack has been performed.
- AeroVironment power supply DFMA study, Milestone I has been completed.
- Fabrication of single-cell, high-pressure module has been completed. The design has been hydrostatically tested up to 1,500 psig.
- Benchtop system I (pressure control) has been tested. Pressure control logic and hardware have been finalized for use in Benchtop II.

- Hazards and Operability (HAZOP) analysis on Benchtop II has been completed, and system design has been modified for safety.
- Benchtop system II (sub-scale electrolysis system) has been fabricated and is now in its de-bugging stage.

Future Directions

- Test and optimize Benchtop system II
- Test prototype electrolysis module and finalize operating pressure based on performance and efficiency
- Continue DFMA engineering
- Continue power supply design (AeroVironment Corporation)
- Initiate DFMA study on compressor with sub-contractor (Pdc Machines Inc.)
- Investigate other potentially economical hydrogen compression solutions
- Design and fabricate deliverable system
- Finalize and arrange a demonstration site

Introduction

This project will contribute to the enabling and acceptance of technologies where hydrogen is the energy carrier between renewable energy resources and clean energy consumers. There are many opportunities for expanding from traditional industrial applications to transportation and stationary use in a more common setting. The lowering of capital costs driven by DFMA efforts and lowering of operating costs resulting from efficiency improvements will make systems more feasible for early adopters and will help U.S. manufacturers maintain a competitive position in traditional and future markets.

Specific goals of the project involve moving towards DOE's technical targets as outlined in Table 3.1.4 of the Hydrogen Production section of the Multi-Year Research, Development and Demonstration Plan. This includes aggressive improvements in cost, efficiency, operation and maintenance of the electrolysis system.

Approach

The main objective of this project is to design, manufacture, test and demonstrate a low-cost, high-pressure electrolysis system capable of delivering 99.99% pure hydrogen. The electrical power management will be flexible to allow demonstration with standard AC grid power or with a renewable energy source. The proposed system will have a capacity of 10,000 scfd. The project places critical emphasis on DFMA and on developing a production strategy for the proposed hydrogen production rates, which are about 100 times those demanded by the current worldwide industrial hydrogen market.

In the final phase of the project, the deliverable system will be installed in a high-quality, transportable industrial building and final acceptance tested. The scope of work includes liaison activities, commissioning and training to support one demonstration for 6 months, probably in the State of Maryland, but intended to be accessible from the nation's capital.

A substantial effort in the proposed scope of work is focused on manufacturing technology, collecting and analyzing cost data, designing and optimizing production processes, and performing a financial analysis of the production line and its facility. The demonstration system will include only those features and components which meet the per-unit cost objective of the solicitation when high quantities are assumed.

Ongoing key elements of this project include safety, reliability, and quality engineering. These will assure a safe system design at higher pressures, a reliability program and quality control aspects to address both the demonstration unit build as well as the quality engineering, material controls and automation needed for a large production operation. The safety efforts include application of traditionally applied codes for flammable and compressed gases, and new codes/standards being developed for renewable energy situations. Teledyne will participate in liaison activities pertaining to public safety, including training, public education and assistance in obtaining regulatory permits for the system demonstration.

The generator design will build on TESI's 30+ years commercial product experience base with improvements in conversion efficiency and a design to reach an electrolysis system operating pressure between 450 and 1,500 psig. A compressor based on mature technology will be used to reach the 5,000 psig final pressure. Activities with the compressor and power supply manufacturer will be focused on improved operating efficiency, a major cost reduction, a higher level of system integration, and inputs needed to support the manufacturing cost objectives.

Results

TESI is utilizing small-scale systems to study and develop critical control algorithms and operational procedures for the hydrogen generator. The Benchtop I system was the primary vehicle used to develop effective and safe high-pressure gas control hardware and logic. This system did not contain an electrolysis module and utilized nitrogen to replace oxygen. This approach allowed control algorithms to be developed and tested, while minimizing the hazard level of the system. Benchtop System I (pressure control) has been tested, and pressure control logic and hardware have been determined. The results derived from this system are being applied to the Benchtop II system.

Benchtop II will operate a small-scale electrolysis module and will serve as a tool to study module operation at elevated pressures (200-1,500 psi). Inferences from this system will include membrane life and performance at operating pressures. The design work has been performed in consideration of manufacturability and safety. The fabrication of the Benchtop II system has been completed.

Analysis of the Benchtop II pressure vessels utilized the design intent of ASME Code Section VIII, division 2 codes. Supporting finite element analysis work was performed to evaluate discontinuity stresses. A HAZOP analysis was then performed on the Benchtop II system, instrumentation, and control design. This process resulted in the identification of some potential hazards in certain operational scenarios. Design modifications were then implemented to mitigate the risks, improving system safety. Fabrication and debugging of Benchtop II is near completion, and the system is scheduled to be put on test in July 2005.

TESI has been working with the integration of electrolysis cell components to reduce the part count to achieve DFMA objectives. Mixed results have been obtained, with work continuing to resolve part tolerances and related issues.

TESI has purchased and set up hardware in its plant to facilitate the production of more consistent membranes. This equipment is operational, and membranes have been successfully fabricated and tested at TESI's standard operating pressures. Testing at elevated pressures will be performed on the Benchtop II system.

TESI has partnered with AeroVironment Corporation to perform a DFMA study with the objective of high-efficiency, low-cost power supplies for electrolytic hydrogen generators. The company will also provide the power supply for the deliverable full-size electrolysis system. The DFMA study has been divided into 4 milestones. The first milestone involving the definition of system requirements and specifications has been completed. Work on the second milestone is scheduled to begin after high-pressure data from the Benchtop II system has been analyzed.

Summary

A new electrolyzer module is being developed at TESI to support DFMA with the intention of operating at a pressure between 450 and 1,500 psig. This module will be integrated into a high-efficiency system with a final hydrogen output pressure of 5,000 psig.

Future work will include testing the newly designed cell and module, along with the newly developed fabrication techniques. Benchtop systems are being used to study module lifetime and validate control techniques and strategies. HAZOP/failure modes and effects analysis studies have been performed to drive any safety-related engineering. TESI will design and fabricate the deliverable system, including consolidation of sensors and controls between its various components, along with engineering considerations to minimize the capital, operational and maintenance costs.

FY 2005 Publications/Presentations

1. S. Ibrahim and S. Cohen, "Alkaline, High Pressure Electrolysis," 2005 DOE Program Review Presentation, Arlington, VA (2005)