IV.H.7 Hydrogen Generation From Electrolysis

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Objectives

Determine pathway to optimum proton exchange membrane (PEM) electrolysis based H_2 fueling through conceptual system design and analysis, and subsystem/component development.

- Optimize PEM electrolysis hydrogen generation system for vehicle fueling
- Improve subsystem/component performance, cost, and durability

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 Cost
- H. System Efficiency
- J. Renewable Integration

Technical Targets

This project is conducting design trade studies and component/subsystem cost reduction activities of a water electrolysis fueling station utilizing PEM technology for hydrogen generation. The results are combined into a fueling station design that meets the DOE 2010 water electrolysis targets. Early work is focused on the generation portion of the system with the goal of meeting the cost and efficiency targets for the power conversion, cell stack, and balance of plant that make up the electrolyzer. Additionally, electrochemical compression is explored as a replacement or supplement to mechanical compression to lower system lifetime maintenance costs.

- Cost: \$0.39/gge H_2
- Efficiency: 76%

Approach

Perform conceptual systems design and analyses

- Generate system cost vs. performance analysis model
- Develop conceptual system design
- Perform design trades for subsystems and components

Perform development test on key subsystems/components

- Develop and test prototype to substantiate analytically predicted performance
- Conduct development tests of low cost materials and assembly techniques

Accomplishments

Cell Stack Cost Reduction

- Examined four cost reduction/efficiency opportunities:
  - Efficiency gains through higher temperature operation
  - Optimization of catalyst loading for performance and cost
  - Lower cost/higher performance catalyst
  - Lower cost/higher performance ion exchange membranes
- Changes evaluated have shown potential of
  - 5% gain in cell stack efficiency
  - 30% cost reduction of MEA
  - 8 to 10% cost reduction of cell stack

Electrochemical Compression

- Achieved ambient compression of 2,400 psi
- Identified parameters affecting performance
- Obtained encouraging preliminary efficiency and throughput results

Future Directions

Address key proton exchange membrane electrolysis fueling roadblocks

- Generation Capacity - scale up electrolyzer cell stack
- Efficiency – determine optimum balance of current density vs. efficiency
- Capital Cost – perform cell stack and power conversion cost reduction
- Renewable Interface – develop efficient energy transfer methods
- Compression - develop electrochemical compressor cell stack

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Introduction

Large-scale commercial hydrogen production required for vehicle fueling poses significant challenges for PEM electrolysis considering the state of the technology today. The cost and generation capacity of today's electrolysis systems do not meet the requirements of a commercial vehicle fueling station. The goal of this project is to first determine a PEM electrolysis system configuration that is viable for commercial scale vehicle fueling in terms of capacity and cost, and then to incrementally develop solutions for those subsystems identified as needing the most improvement.

Cell Stack Cost Reduction – The cell stack is one of the most expensive sub-components of the hydrogen generating portion of the system, and is attributable for approximately 20 - 40% of the overall electrolyzer cost. Approximately 20 - 40% of the cell stack cost is due to the materials and processes used to manufacture the membrane electrode assembly. This makes the membrane electrode assembly, or MEA, a prime target for cell stack cost reduction.

Electrochemical Compression – Mechanical compression is recognized as a significant cost driver for fueling due to the maintenance required over the life of the unit. An electrochemical compressor (ECC) offers advantages over mechanical compressors since there are no moving parts. The number of cells in the stack determines the size of the ECC for efficient compression in specific applications, whereas mechanical compressors have discrete frame and motor sizes. The ECC can also be an intermediate means to boost initial hydrogen inlet pressure to increase mechanical compression efficiency and lower cost by reducing the number of mechanical compression stages.

Approach

Conceptual Design and Analyses

This element focuses on the design of the system as a whole, the requirements placed on each subsystem, and analyses of their performance and cost. The entire system implementation is analyzed using a cost model that ties directly to the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R, D&D Plan technical targets. For each subsystem a variety of implementations are examined against each other in terms of cost, complexity, and impact on adjoining subsystems. This process identifies potential subsystem solutions with top candidates selected for prototyping and evaluation.

Development Testing

The design trades performed for various subsystems require data for completeness and accuracy. New concepts identified are prototyped at a scale that yields relevant information that can be used in the design trades. These prototypes do not have to be full-scale to be relevant. They are performed at a scale that allows the effects on cost and performance of future full size units to be estimated. Other development tests that examine new low-cost materials and/or assembly techniques are performed to confirm the possible benefits.

Results

Cell Stack Cost Reduction

The following topics were identified as potential cost reduction activities, and were evaluated in this study:

- Efficiency Gains through Higher Temperature Operation
- Optimization of Catalyst Loading for Performance and Cost
- Lower Cost/Higher Performance Catalysts
- Lower Cost/Higher Performance Ion Exchange Membranes

Breaking the project down into the sub-topics shown above enabled the evaluation of each cost reduction effort independently. This allowed a more fundamental understanding of the impact each change has on the operating efficiency and cost of the electrolyzer cell stack. Whenever a new material/process was used in the MEA fabrication process, the manufacturability as well as the physical properties of the MEA were recorded.

The first three topics were evaluated using 3-cell, 0.1 ft^2 electrolyzer cell stacks. The stacks were run on internally developed proprietary R&D test stands at the following conditions:

Operating Temperature:	50°C
Operating Current Density:	1850 mA/cm^2
Hydrogen Pressure:	200 psig
Oxygen Pressure:	10 psig

The test stands allow accurate control of the operating temperature of the cell stack, thereby removing the inaccuracies associated with voltage/temperature corrections. Automated data acquisition logged relevant information including inlet/outlet temperature, pressure, current, and voltage at ten second intervals. The test stands also ran automated voltage/current polarization curves at predefined time intervals. A baseline cell was included in each test stack to monitor any process/hardware variations that could impact the test results. Long-term performance data was generated by running the stacks for 1,000 hours at the operating conditions shown above. Previous testing has shown that cells remain very stable after this point, making it possible to accurately forecast future performance.

The fourth topic was evaluated using a 20-cell electrolyzer of the same cell configuration previously mentioned. Testing on the 20-cell level provided more statistical cell data as well as the opportunity to evaluate the stack performance in a commercial system.

It was shown that operating at elevated temperatures resulted in as much as a 5% improvement in stack efficiency over the baseline operating temperature. It was also shown that by optimizing catalyst loading, the cost of the MEA could be reduced by as much as 10% without impacting cell performance. Alternative anode catalyst materials that perform better and cost less than current catalysts were also evaluated. These catalysts showed voltage efficiency improvements of 8-9 % while reducing the cost of the MEA by 10%. The performance of MEAs made with lower cost/higher efficiency membrane material in conjunction with an alternative anode catalyst was also evaluated. These MEAs cost 33% less than the baseline MEAs and showed a voltage efficiency improvement of 10%.

Electrochemical Compression

A series of proof-of concept tests were conducted to provide an assessment of the feasibility and the variables that could affect electrochemical hydrogen compression. A single cell having a Nafion® 117 based MEA with an active area of 0.03-ft^2 was built with hardware that is capable of operating at nominal pressure of 2,400-psi.

A dedicated bench-scale test stand designed for a maximum operating pressure of 2,400 lb/in^2 was built and commissioned. Humidification is accomplished by passing the hydrogen gas through Nafion tubing submerged inside of a stainless steel water vessel that is heated at controlled temperature. Line heaters and a heating pad on the cell stack body are used to maintain and control system operating temperature. The product pressure is monitored by a pressure transducer and a digital pressure gauge, and is regulated via a backpressure regulator. Moisture content in the pressurized product stream is removed in a desiccant column and the dried product flow rate is measured by a mass flow meter. All of the pertinent system operating parameters were captured by a data logging system.

Comprehensive testing was carried out to determine the interrelationships between the key parameters affecting electrochemical compression, including humidification levels, hydrogen stoichiometries, cell voltage potentials during the pressure increase, hydrogen capacity, product pressure and energy requirement for the compression work.

These preliminary test results indicate that electrochemical compression of hydrogen up to 2,400-psi is technically feasible using current state-of-the-art PEM technology. Successful test results were obtained at stoichiometric inlet flow rates under fully humidified conditions at an operating cell temperature of 60°C. Voltage performance was stable under relatively high current densities between 700 mA/cm^2 to 1,100 mA/cm^2. The resulting hydrogen feed utilization at these current densities ranged from 80% to 95%, indicating that flexible throughput of hydrogen is feasible.

Conclusions

- Cell stack cost reduction is possible through catalyst reductions/modifications without compromising performance. Changes evaluated have shown potential of
  - 5% gain in cell stack efficiency
  - 30% cost reduction of MEA
  - 8 to 10% cost reduction of cell stack
- Operating the system at a higher temperature is one way to increase efficiency, though balance of plant considerations require examination
- Electrochemical compression holds promise based on preliminary findings at medium pressures, full fueling pressure requires test

FY 2005 Publications/Presentations

1. Cell Stack Cost Reduction Design Study & Development, Henderson, April 29, 2005 – Milestone Report
2. Proof-of-Concept Electrochemical Compression of Hydrogen as Possible Alternative to Mechanical Compression, Chow, April 29, 2005 – Milestone Report