II.E.3 High-Capacity, High Pressure Electrolysis System with Renewable Power Sources

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Contract Number: DE-FG36-08GO18066

Subcontractor:
HyPerComp Engineering, Inc., Brigham City, UT

Start Date: June 1, 2008
Estimated Project End Date: September 30, 2012

Fiscal Year (FY) 2011 Objectives

- Achieve at least a 15X increase in the gas production rate of a single high-pressure production cell.
- Demonstrate the high pressure cell composite wrap which enables significant weight reduction.
- Build and test a $1/10^{th}$-scale pilot plant.
- Have fabrication ready drawings for full-scale plant (300 kg/day, 750 kW).

Technical Barriers

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

(G) Capital Costs of Hydrogen Generation by Electrolysis Systems
(H) System Efficiency
(J) Renewable Electricity Generation Integration

Technical Targets

TABLE 1. DOE Technical Targets: Distributed Water Electrolysis Hydrogen Production

Characteristics	Units	2012 Target	2017 Target
Hydrogen Cost	$/gasoline gallon equivalent (gge)	3.70	<3.00
Electrolyzer Capital Cost	$/gge $/kW	0.70 400	0.30 125
Electrolyzer Energy Efficiency	% (lower heating value)	69	74

Distributed Water Electrolysis Hydrogen Production

In this project Avãlence is developing an enlarged version of its present electrolyzer design that will have 15X the capacity of the current single tubular cell. To achieve this, the diameter of the current Avãlence design individual tubular cell is being enlarged to enable an innovative cell core design: multiple coaxially arranged cylindrical electrodes, nested in a uni-polar configuration. This design is the core of a distributed water electrolysis hydrogen production system that will meet the following DOE 2017 targets:

- Hydrogen cost: $3.00 gge
- Electrolyzer energy efficiency: 74 kWh/kg

FY 2011 Accomplishments

Detailed engineering and design and construction of the test cell continued during 2011. Significant engineering focus was directed toward a detailed design to seal the inner electrodes and membranes and the pressure flange and provide inlet and exit ports for the water and H_2 and O_2 gases. The cell prototype will be tested at 1,000 psi on an existing test stand at Avãlence that will provide electrical and pressure control and electrolyte level balancing. 2011 accomplishments include:

- Detailed design drawings for the prototype cell (Figure 1) to include the following elements:
  - A top gas exit manifold made of polyvinyl chloride (PVC) that will have gas collection channels machined into the manifold. Oxygen will be collected and sent to a center outlet port. The hydrogen manifold will be split into four quadrants with outlet ports in each of the four quadrants. The manifold, which will have an electrode sealing mechanism or clamp, is at the top end of the cell.

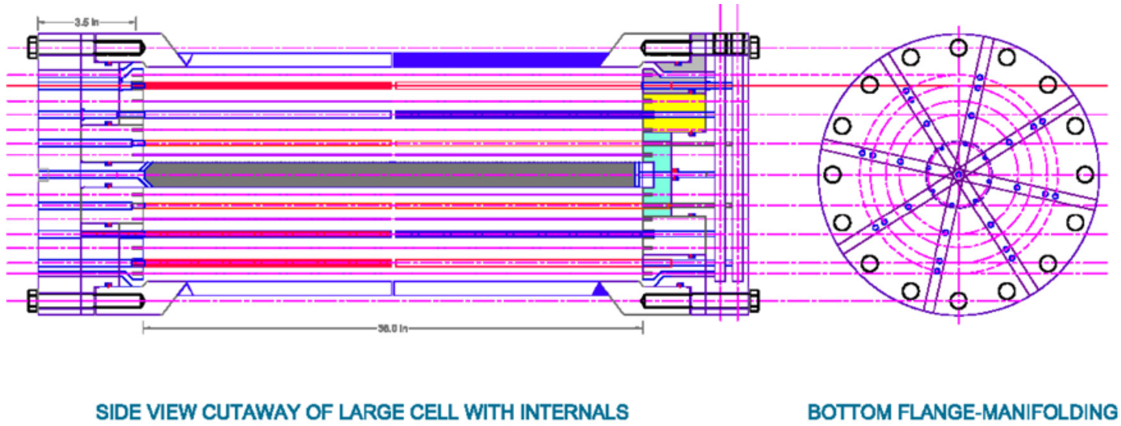

FIGURE 1. Cutaway View of Cell Nested Components

  - An innovative method of joining and securing the electrode and membrane ends to the top and bottom of the cell via a mounting collar made of PVC.
- Detailed design of the exact geometry of the internal nested cylindrical components which consist of two inner anodes, two cathodes, and the four membranes that form the boundaries between the anolyte and catholyte chambers. The design utilizes 8-inch, 6-inch, 4-inch and 2-inch 316 stainless steel.
- Detailed engineering design of the inner and outer pressure flanges that will allow the assembly of inner electrodes and membranes in two modules:
  - One outermost piece of the outer flange assembly that holds an anode, inner cathode, and two membranes.
  - A second assembly that includes a flange which is sandwiched underneath the outermost flange. This assembly holds the second anode and the center cathode, plus two membranes in place.
  - Design of plastic mounting disks which are placed inside and are locked into position by the outer flange pieces to seal the electrodes and membranes in place.
  - The outermost piece of the outer flange is bolted through the second assembly (sandwich) flange into the inner flange of the cathode/pressure cylinder, pressure sealing the entire cell.
  - The design calls for a top outer flange/mounting disk assembly with gas exit paths, and a bottom outer flange/disk assembly with liquid distribution and recirculation.
  - In a departure from the current smaller scale Avãlence product design [1], the cell membranes are sealed at both ends of the cell to prevent anolyte and catholyte from mixing. This will ensure high purity by preventing H_2 and O_2 gases dissolved in the electrolyte from crossing the cell boundaries formed by the membranes by eliminating an open circulation path below the membrane. Anolyte and catholyte entrained in the exiting gas bubbles (through gas paths in the top of the cell) will return to the appropriate cell chambers via external circulation and reinjection through the bottom outer flange/disk assembly.
  - The design makes extensive use of O-rings to seal leak paths through liquid inlets and gas outlets, as well as to seal the flanges at both ends of the cell.
- The outer cathode/pressure cylinder was cut from an 8-inch pipe and the inner flanges machined from a stainless steel solid bar stock at Avãlence and welded together and dye penetrant-checked, see Figures 2 and 3.
- The cylinder was shipped to HyperComp in Brigham City, Utah, for wrapping with carbon fiber, see Figure 4.

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Introduction

Avãlence has existing technology that is globally unique in its ability to deliver hydrogen directly at storage-ready pressures of 2,500 and 6,500 psi without a separate compressor. Using an alkaline electrolyte process, the Avãlence Hydrofiller systems integrate the production and compression processes by operating the electrolytic cells at the desired delivery pressure. The systems can interface directly with renewable electricity supplies and have been shown in previous work (DOE Small Business Innovation Research project completed in April 2005) that the electrolyzer operates through the full range of voltages output from the connected photovoltaic (PV) array without using any power conditioning equipment. These characteristics result in a renewable hydrogen production and delivery system that is significantly more efficient and reliable, and substantially less expensive than existing commercially available electrolyzer and compressor system sets. The smaller scale Hydrofillers are based on a single cathode/anode tubular cell design with production

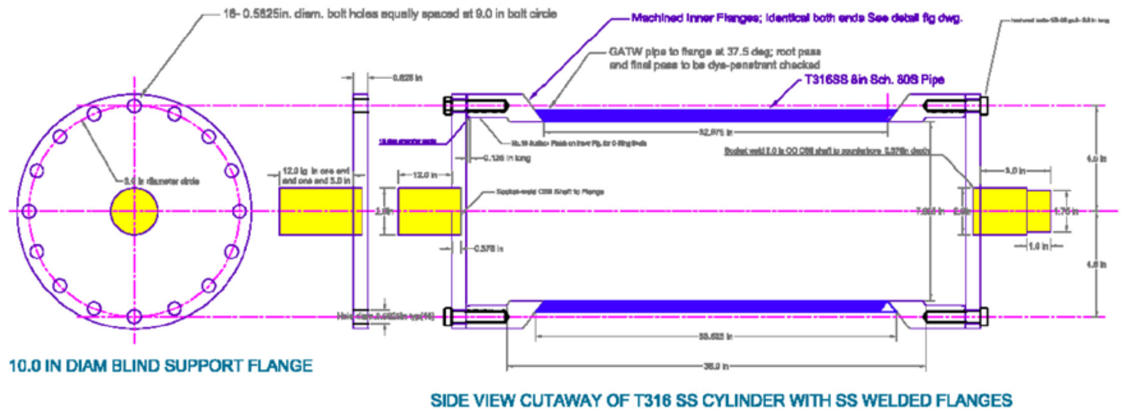

FIGURE 2. Cell with Flange Ends for Carbon Fiber Wrapping

FIGURE 3. Photograph of Cell Prior to Carbon Fiber Wrapping

capability of about 0.1 kg/day per cell. A revolutionary design approach to this high-pressure cell core is needed for an order-of-magnitude capacity scale up of the individual electrolyzer modules.

Approach

In this project, Avãlence is developing an enlarged version of the current Avãlence design that will have at least 15X the capacity of our present single tubular cell. The diameter of the large individual cell will be substantially increased in order to enable an innovative cell core design – multiple coaxially arranged cylindrical electrodes, nested in a uni-polar configuration – enabling up to 1½ kg/day of production per individual cell. In order to accomplish this cell diameter increase with a practical pressure boundary while operating at either 2,500 or 6,500 psi, Avãlence has partnered with a composite cylinder manufacturer, HyPerComp Engineering Inc. They will develop a custom designed containment vessel/cathode using their composite technology expertise that will allow an increase in the diameter of the individual electrolysis cell, enable operation at 2,500 psi and above, and reduce the cell weight and cost relative to conventional metal containment (similar to what is seen today with composite storage tanks used on vehicles). Ninety-six of these high-capacity cells will now produce a single unit (module) with a production capacity of 150 kg/day.

To complete this development process, Avãlence is proposing to build a quarter-scale pilot plant to be composed of 20 cells that will replicate the full plant design and operation, but minimize the cost to DOE for this technology demonstration. The pilot plant will be sent to the National Renewable Energy Laboratory for verification testing. The final result of the project will be a commercially operating 30 kg/day pilot plant integrated with a wind turbine and/or PV array, and delivering H_2 gas at pressure directly to storage cylinders. Operation of this plant and extensive testing of this and earlier development versions throughout the course of the project will thoroughly document the performance and operation of the technology. This combination of an operating pilot plant and substantial performance and operating data will position the technology for commercialization.

Results

Initial test work on nested components, with passive circulation, was conducted during the first quarter of FY 2011. The test results from one nested set did demonstrate substantial recirculation (driven only passively at this point). The recirculation had a very positive effect in that purity of hydrogen (before the catalyst) increased from 98.5% typical at 2,200 psig to >99.5% at 2,200 psig. The recirculation resulted in less dwell time inside the cells for the gas bubbles and therefore less opportunity to diffuse or leak by whatever minute paths exist. This is an indication that Avãlence should be able to return to high pressure operation (6,000 psig) with no compressor, and stay below the required safety limit of 2% impurity before the catalysts. The test cell, with five nested electrodes, will use active circulation, which should further reduce dwell time, so even better results

FIGURE 4. HyperComp Wrapping Sequence and Finished Cylinder

are anticipated. In support of the multi electrode testing, Avãlence has selected circulation pumps for testing of the five nested electrodes.

Based on the tests conducted during the first quarter of FY 2011 and additional analysis, there is a problem of excessive voltage drop associated with axial electrical conductivity in the nested set of 316 stainless steel electrodes. As a result, additional design work was undertaken to decrease electrical resistance within the cells and associated with pass through (sealed) conductors. This is focusing on the selection and construction of the anodes and cathodes that provide the axial conductivity and electrical pass through, and which are also of acceptable cost. The test cell design is limited to 3' height due to concern over voltage loss axially. This means that the pilot plant cells at 6' will require that electrical connections are made at both ends of the electrodes or another solution is devised in order to improve the conductivity. For example, it is possible to solve this problem with a change in material (to nickel for example), but this is costly. Avãlence is working on other concepts such as layering (cladding) the electrodes to deliver both the conductivity required and to manage the cost.

Lastly, design work focused on how to align the plurality of electrodes and membranes top and bottom for better manufacturability. This is being addressed by securing the membranes and inner electrodes to a top alignment mount made of PVC that will be glued to the upper gas manifold (also made of PVC). The relatively thin membranes will be reinforced at the bottom with a PVC guide ring glued to the membranes. The membranes and electrodes are attached to a PVC bottom alignment guide, and the entire assembly can then be inserted into an outer anode and flange assembly. Avãlence is researching the manufacture and supply of stiff tubular membranes made by casting a membrane material onto a rigid ceramic, extruded PVC, or other support.

Conclusions and Future Directions

Conclusions

Through changes in conceptual design and detailed engineering design currently underway, Avãlence is addressing the design challenges of this unique high pressure concentric ringed electrolysis cell, all of which impact manufacturability, gas purity, and high pressure operation:

- Electrode and membrane sealing to cell ends
- Gas collection
- Axial conductivity
- Electrolyte balancing
- Cell cooling
- Etc.

Future Directions

- Demonstrate large diameter cell operation at 1,000 psi:
  - The cell will be tested on a test stand that Avãlence has adapted from the balance of plant of a Hydrofiller 15.
  - Will circulate electrolyte on both sides using cat pumps.
  - No gas recirculation will be required until the design pressure goes above 2,500 psig.
- Test long-term 6,500 psi operation approaches:
  - Using existing small cell apparatus.
  - Purified gas "recirculation/dilution" approach as required to achieve lower explosive level requirements.
  - Neutral electrolyte chamber approach – membrane related effort.

FY 2011 Publications/Presentations

1. *High Pressure, High Capacity Electrolysis System*, presented at the 2011 Fuel Cell and Hydrogen Association Conference, February 15, 2011.