II.E.2 High-Capacity, High-Pressure Electrolysis System with Renewable Power Sources

Martin A. Shimko
Avālence LLC
1240 Oronoque Road
Milford, CT 06460
Phone: (203) 874-6786; Fax: (203) 878-4123
E-mail: mas@gasequip.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: Paul Bakke
Phone: (303) 275-4916; Fax: (303) 275-4753
E-mail: Paul.Bakke@go.doe.gov

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HyPerComp Engineering, Inc., Brigham City, UT

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Estimated Project End Date: June 1, 2012

Objectives

In this project Avālence is proposing to develop an enlarged version of our present design that will have 15X the capacity of our single tubular cell. This will be accomplished by first testing a cell at 1,000 psi using conventional pressure containment materials. We will then fabricate and test a single cell at 6,500 psi that uses composite fiber wrapping to achieve the pressure containment. We will then build a sub-scale system containing about 20 cells that will produce about 30 kg/day. After a three-month period testing at the National Renewable Energy Laboratory (NREL), this system will be installed in revenue service in Portland, Maine. These objectives are listed below. The specific technical objectives for the project are listed in Table 1.

Project Objectives

- Achieving 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).

Project Technical Objectives

- Determine a manifolding and sealing arrangement for nested cell that satisfies need for H_2 and O_2 gas separation, electrical connection to electrodes, and electrolyte replenishment.
- Determine containment penetration size and design that is compatible with composite wrapped vessel constraints, cell electrode current transfer and flow requirements for gas off-take and electrolyte replenishment.
- Design a functional shape of outer metal jacket for dual purpose:
  - Outer electrode's inner surface.
  - Vessel liner that is the foundation for composite wrap.
- Demonstrate the performance of the nested cell core so that accurate projections of energy use can be integrated into the cost model.
- Demonstrate the ability to implement a composite fiber outer wrap over the nested cell core.
- Produce a pilot plant design for use as a basis for a sound economic analysis of plant fabrication and operating cost.
- Demonstrate the operation and efficiency of the pilot plant:
  - Laboratory testing at Avālence.
  - Field testing at NREL.
- Have a site ready to accept the completed plant for commercial operation:
  - 100 kW of renewable power in place.
  - Sale or use of the plant products defined.

Technical Barriers

This project addresses the following technical barriers from the Production section (3.1) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(G) Capital Cost
(H) System Efficiency
(J) Renewable Electricity Generation Integration (for central)

TABLE 1. Technical Targets and Status

Characteristics	Units	2012/2017 Targets	Avālence Status	Avālence Commercial Projection
Hydrogen Cost	\$/kg H_2	3.70/<3.00	4.38*	2.84*
Electrolyzer Capital Cost	\$/kg H_2	0.70/0.30	0.98*	0.33*
	\$/kWe	400/125	2,600*	860*
Electrolyzer Energy Efficiency	% (LHV)	69/74	65*	70*

*Includes capital cost/energy of compression process; LHV – lower heating value

Technical Targets

The goal of this project is to demonstrate the technology and estimate the production, efficiency, and operating cost of a 300 kg/day system. The assumption is that five modules will be used to achieve the 1,500 kg/day level used by DOE in their cost analysis and target cost definitions. The analysis uses a 20 year useful life and annual operating cost estimates of 5% of capital cost. Electricity costs of 3.9 cents/kWhr and an availability of 90% are also used (see Table 1).

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Introduction

Avālence has existing technology that is globally unique in its ability to deliver hydrogen directly at storage-ready pressures up to 6,500 psi without a separate compressor. Using an alkaline electrolyte process these 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 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/compressor sets.

These smaller scale Hydrofillers are based on a single cathode/anode tubular cell design with production capability of about 0.1 kg/day. Using the present configuration, this technology is utilized in units (modules) with capacities of up to 10 kg/day by using arrays of individual cells in groups of up to 96. Though effective for small-scale, distributed hydrogen production, 150 modules would be needed to achieve DOE's 1,500 kg/day target for cost comparison. It is unlikely that this ganging of small electrolyzers can meet DOE's cost targets because of the immense interconnecting tubing requirement, excessive replication of the single cell (15,000), and wasteful repetition of the balance of plant components. 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 Avālence is developing an enlarged version of our present design that will have at least 15X the capacity of our present single tubular cell. To achieve this we need to substantially increase the diameter of the individual tubular cell 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. To accomplish this scale-up at 6,500 psi we are partnering with a composite cylinder manufacturer, HyPerComp Engineering Inc. (HEI). They will develop a custom designed containment vessel/cathode using their composite technology expertise that will allow us to effectively increase the diameter of the individual electrolysis cell, enable operation at 6,500 psi, and reduce the cell weight and cost relative to conventional metal containment (similar to what is seen today with composite storage tanks). 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 we are proposing to build a quarter-scale pilot plant of this design composed of 24 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 NREL for verification testing over the last three months of this 30 month project. To effectively utilize the pilot plant at the conclusion of the DOE sponsored portion of this overall program, we are partnering with the Hydrogen Energy Center of Portland, Maine and MaineOxy, an industrial gas supplier, in Auburn, Maine, who are presently teaming in an effort to site the pilot plant in Portland for commercial use, supplying high purity oxygen for industrial sales and hydrogen for use in peak shaving and as transportation fuel. They are presently seeking

State of Maine funding and local investment to install at least 100 kW of renewable power (wind and/or PV) and perform the necessary site preparation for installation and operation. The final result of the project will be a commercially operating 40 kg/day pilot plant integrated with a wind turbine and/or PV Array, and delivering product at 6,500 psi 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 this technology for commercialization to a waiting market.

Issues

Work on this project was delayed for approximately eight months while we identify and test a new membrane that can effectively block hydrogen egress into the oxygen byproduct. As an alternative approach we will be testing an approach to recycle the oxygen by-product gas after purification to reduce the hydrogen levels in the oxygen byproduct gas. In addition we are working with electrical isolation hose suppliers to produce a 6,500 psi hose for our system, since the original hose produced for us has shown a gas leakage rate that is unacceptable for efficient operation (though well within the limits of safe environmental operation). As a back up to this we are examining non-flexible electrical isolation arrangements.

Accomplishments

Highlights of the progress are as follows:

- Successfully demonstrated joinery for membrane material.
- The design of the single cell test apparatus was completed.
- The design of the 1,000 psi single cell was completed.
- HEI completed the design of the 6,500 psi containment vessel.
- Fabrication of the test apparatus continued.
- Materials for the 1,000 psi single cell test article were ordered.

We completed our extended testing of the adhesive used to create the seams in the membrane material required to construct the cylindrical membranes for the test apparatus. This testing was performed on our standard configuration membranes in actual electrolyzer operation (28% KOH and 50°C) for over 1,000 hours. Destructive testing revealed that the base material ripped without the seam failing even after the extended environmental exposure. Figure 1 shows a membrane and the seam (indicated by the black adhesive).

Figure 2 is an example of the detailed design drawings completed so that fabrication of the cell can begin when the ordered materials have arrived. Figure 3 is the designers rendering of the 1,000 psi single cell test article.

We are progressing well on the fabrication of the test apparatus. Figure 4 shows the fabrication of the valve panel for the test apparatus in progress.

Future Work

Over the next year we will complete the fabrication and testing of the 1,000 psi test cell and demonstrate the ability to operate at 6,500 psi. If funding allows we will fabricate and demonstrate the 6,500 psi test cell.

FIGURE 1. Membrane Seam after >1,000 Hours of Testing

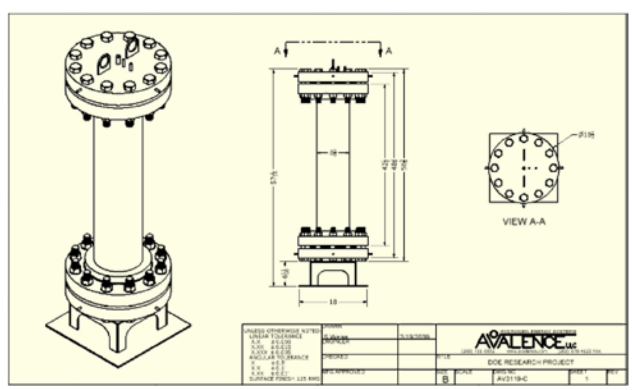

FIGURE 2. Typical Cell Design Drawing

FIGURE 3. Rendering of 1,000 psi Single Cell Test Article

FIGURE 4. Valve Control Panel Fabrication in Progress