WESTINGHOUSE AIR-COOLED PAFC TECHNOLOGY

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Introduction

Over the past 20 years, the Department of Energy (DOE), the Electric Power Research Institute, the Gas Research Institute, private industry and others in the U.S.A. have been pursuing the development of fuel cells for use in environmentally clean electric utility and industrial power plants. These power plants are expected to be in the 3 to 50 MW range.

Of the several types of fuel cells, the phosphoric acid fuel cell (PAFC) technology is the furthest developed, and thus most mature in terms of readiness for commercialization. The Westinghouse Electric Corporation entered into a licensing agreement with Energy Research Corporation relative to their air-cooled PAFC technology. Air rather than water was selected for cooling as this avoids the need to incorporate additional cooling paths into the stack with resultant added series resistance and corrosion-complications. As a result of this agreement, Westinghouse has been developing for over a decade this most promising and highly efficient alternative power generation technology option. Plans to bring this technology to the commercial marketplace, the power plant key features and fuel cell technology status are now examined.

Program overview

The Westinghouse PAFC program consists of two complementary but highly integrated programs. These programs are the Westinghouse sponsored Power Plant Program and the United States DOE sponsored PAFC Technology Development Program. Under the Power Plant Program, Westinghouse along with its other team members will design, build and operate demonstration and commercial systems for various utility and industrial plant applications. The cell technology development effort is being performed by a joint Westinghouse and Energy Research Corporation team under the DOE Morgantown Energy Technology Center Contract DE-AC21-82MC24223. The key objective of these programs is to commercialize the technology in the 1990s for the electric utility and industrial markets.

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Commercialization

The Westinghouse commercialization program is directed towards having standardized factory produced 3 and 13 MW power plants available for sale commercially by the mid-1990s. Figure 1 illustrates the commercialization plan which consists of three distinct but highly inter-related phases. These are the prototype demonstration, early commercialization and mature commercialization phases.

Acceptance of the commercial plants will depend largely on the level of confidence in performance and economic predictions. Therefore, Westinghouse intends to build a 3 MW prototype power plant as the next step in the commercialization chronology. As described later, the Westinghouse air-cooled PAFCs are ready for prototype operation under real load conditions.

Following this demonstration, the Westinghouse team will evaluate the performance of the PAFC modules along with other critical plant systems such as fuel processing and power conditions. In addition, updated plant system and component cost projections, plant economics and relevant market data will be analyzed. At this time, Westinghouse intends to construct a highly automated manufacturing facility by the end of 1994 to initially mass produce fuel cell modules. This facility, along with other cost reductions envisaged, is expected to result in an acceptable initial selling price for the plant.

The final step in the plan is the mature commercialization phase. This phase is expected to be completely market driven. It is projected that the

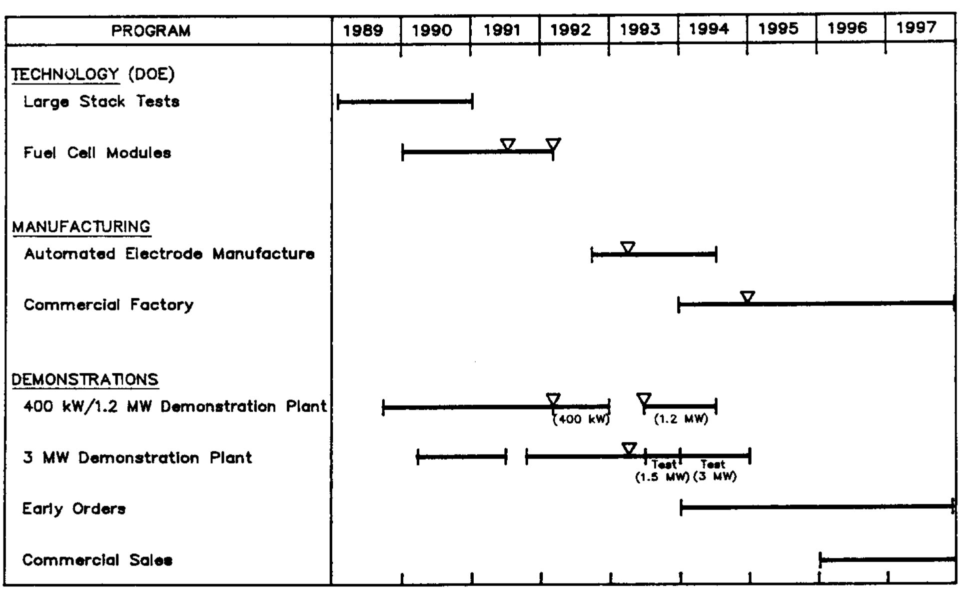

Fig. 1. Westinghouse PAFC commercialization plan.

early PAFC units produced in this phase may be somewhat higher priced relative to competitive electrical power generation technologies. This price, however, will be offset considerably by the value of the environmental acceptability and other well known benefits of fuel cell power plants particularly as more stringent siting and environmental regulations become law.

Plant design

Westinghouse has always placed a most important emphasis on the reliability and maintainability aspects of the power plant. This consideration, along with others, resulted in the choice of an air-cooled PAFC design along with a modular power plant approach. Multiple units of the 3 and 13 MW plant sizes may be grouped at the same site or dispersed areas to cover the expected power plant range of 3 to 50 MW or larger.

The Westinghouse 3 MW power plant for an all-electric application is shown in Fig. 2. This plant is designed to operate on a variety of fuels such as natural gas, methanol, light distillates, coal gas and other light hydrocarbons. For an electric utility application, the plant will operate as an intermediate or base loaded plant. These characteristics are anticipated to make the plant attractive for a broad range of utility and industrial applications.

The plant can be sited on about 4000 square meters (1.0 acre) of land and consists of a number of major systems. These include the Fuel Processing Power Conditioning, Rotating Equipment, Steam Generation,

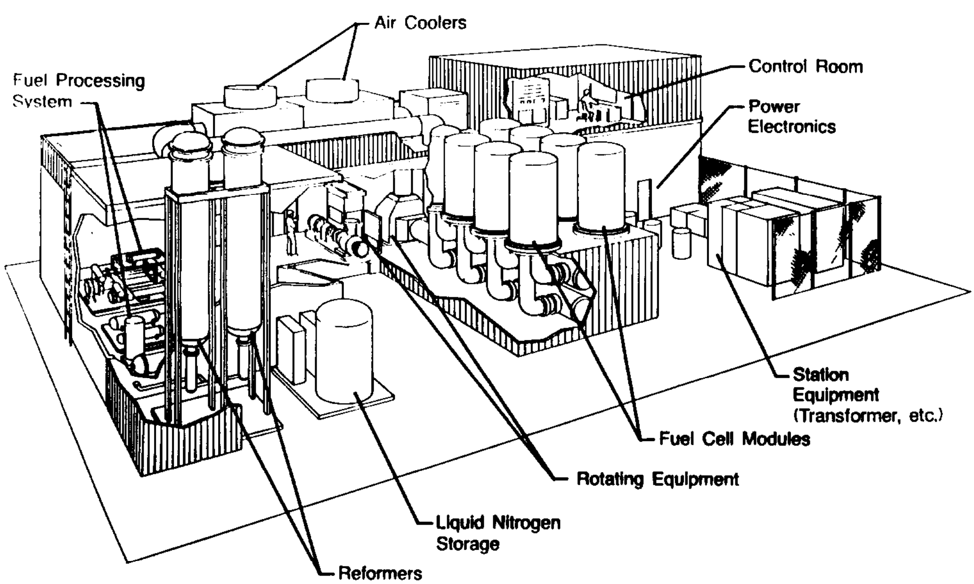

Fig. 2. Westinghouse prototype power plant.

Instrumentation and Control, Balance-of-Plant, and Fuel Systems [1]. The nucleus of the plant is the fuel cell system. This system contains 8 fuel cell modules that are appropriately coupled electrically while thermally in parallel. Each of these modules has a 375 kW nominal rated electric output at beginning-of-use. The air cooled fuel cells are inherently simple and reliable, as the power plant process flow schematic in Fig. 3 illustrates. The Westinghouse 375 kW module is the basic power plant building block. This module is shown in Fig. 4. Four series connected stacks, each containing approximately 450 cells, comprise the Westinghouse 375 kW module. These four cell stacks are housed within a vessel that contains the pressurized fuel and air process gasses.

Initially, these modules are planned to be operated at the following beginning-of-use conditions:

• Pressure	80 psia
• Temperature	205 °C
• Current density	267 mA/cm^2
• Fuel/air utilization	83/60%
• Cell voltage	720 mV

As shown in Fig. 3, the Fuel Processing System supplies the hydrogen rich fuel gas to the anode side of the PAFC. Cooling air is supplied to the pressure vessel and flows radially inward through cooling passages provided between groups of six cells to a plenum formed by the four cell stacks. A

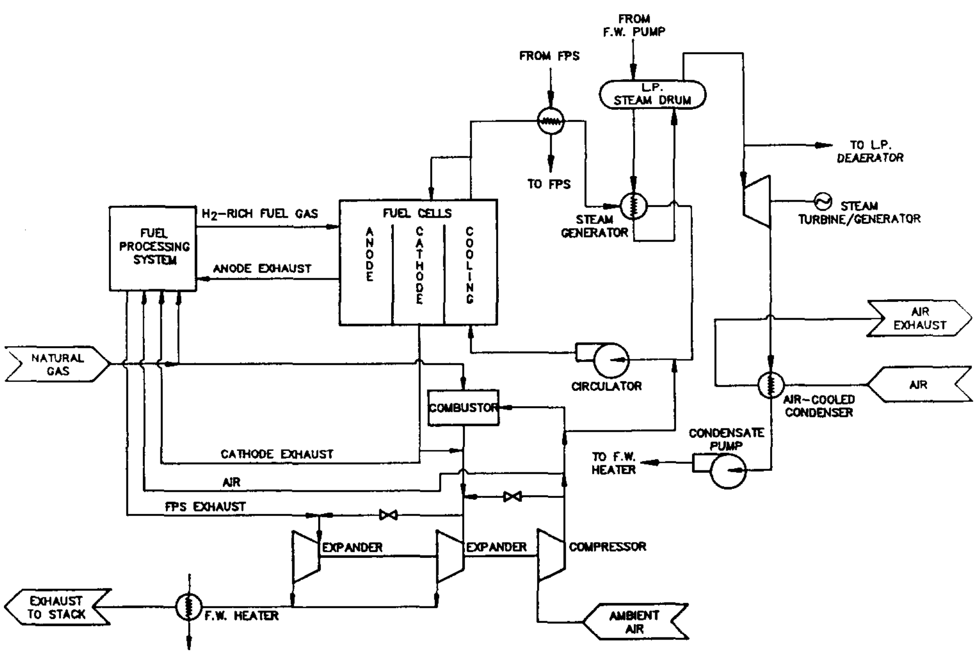

Fig. 3. 13 MW Westinghouse power plant schematic.

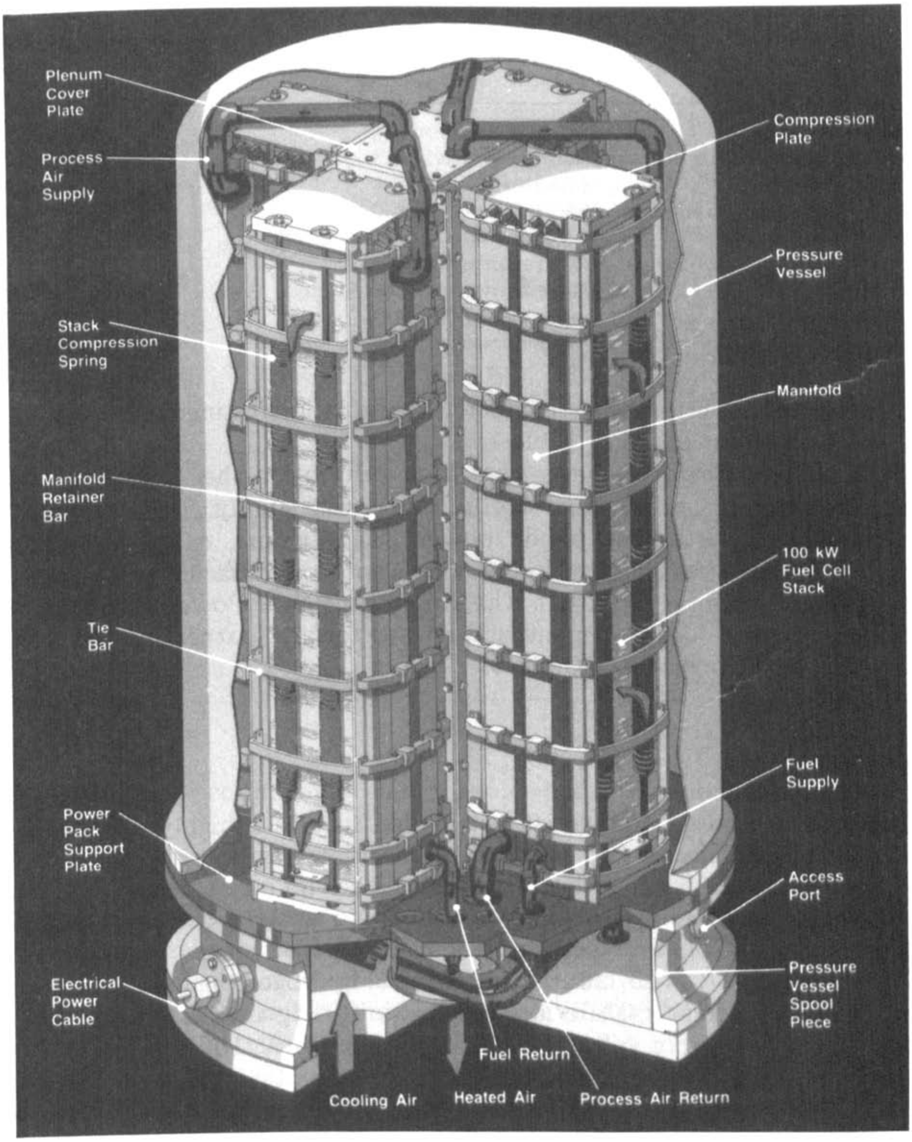

Fig. 4. Westinghouse 375 kW fuel cell module.

small fraction of the heated cooling air is extracted and directed to the cathode side of the cell. Energy to maintain the flow of fuel cell cooling air is supplied by a pressurized circulator in the Rotating Equipment System. The Steam Generation System utilizes the fuel cell waste heat to generate additional electric power. The Power Conditioning System interfaces with the fuel cell modules through consolidation circuits. These circuits control the module currents, which are combined at a common d.c. bus. The

TABLE 1

PAFC plant characteristics

Rated power	13.8 MW
Heat rate (LHV)	6900 Btu/kW h
(HHV)	7674 Btu/kW h
Availability	90%
Plant design life	30 years
Ramp rate	1 MW/s
Operation	unattended remote dispatch
NOx emissions	5 ppm at 15% O_2

projected top level performance characteristics of the Westinghouse 13 MW power plant are summarized in Table 1.

Westinghouse firmly believes that fuel cells offer the capability for self-generated power and local control of the power supply. This is rapidly becoming very important as public power, for example, experiences the impacts of deregulation, generation and transmission capacity access, and mounting environmental problems. The American Public Power Association has recently invited fuel cell manufacturers to form a partnership to commercialize multi-megawatt PAFC plants.

Fuel cell technology

The Westinghouse commercialization plan success is highly dependent upon the U.S. DOE sponsored Technology Development Program to provide a PAFC technology that meets certain performance and economic objectives. The early PAFC technology objectives defined to achieve the plant established goals include: (1) average beginning-of-use performance of 690 mV at 267 mA/cm^2, 190 °C, 4.7 atmospheres, 83% hydrogen utilization using reformed natural gas and 50% oxidant utilization using air; (2) performance stability consistent with a voltage loss of less than 8 mV/1000 h; and (3) a 375 kW module that can be manufactured for about $2600/kW without employing mass production techniques. Modest performance and performance stability improvements to 720 mV and 2 to 4 mV/1000 h, respectively, are needed to achieve the mature commercial power plant goals.

Extensive experiments, subscale cell screening tests, cell materials and components, characterizations, and stack tests have been performed over the past decade. These various efforts resulted in the selection of a baseline cell technology and associated stack design to achieve the performance objectives.

Cell technology selections were made. These selections included the design configuration, materials of construction, manufacturing process(es), subassembly and assembly techniques. In excess of 1 000 000 subscale cell and 27 000 stack test hours were accumulated to assist in the selection

TABLE 2

Cell baseline technology

Catalyst	platinum on carbon
Catalyst layer	Energy Research Corporation rolled configuration
Electrode support	wetproofed carbon paper
Electrodes	0.5 mg/cm^2 platinum for cathode and 0.25 mg/cm^2 for anode
Matrix	silicon carbide–carbon layer composite
Bipolar plates	heat treated graphite–phenolic resin composite
Seals	three piece teflon
Acid make-up	four corner feed

TABLE 3

Small stack performance

Stack	Cell voltage (mV)
W010-22	694
W010-23	699
W010-24	702
W010-25	689

process. The specific components involved and selections made are defined in Table 2.

Four essentially identical ten cell stacks were constructed. Two of these stacks were tested at the rated operating conditions for in excess of 5000 h. The third was tested for over 16 000 h which at this time represents the world's endurance record for a pressurized stack of PAFCs.

The beginning-of-life performance for each of these stacks is shown in Table 3. As can be noted, the beginning-of-life performance for each of the stacks essentially met or exceeded the 690 mV goal. The average performance for these stacks is 696 mV/cell with a standard deviation of 5 mV.

The performance decay for one of these stacks, namely Stack W010-22, is presented in Fig. 5. As noted, the 8 mV/1000 h voltage decay goal is nearly achieved with 8.3 mV/1000 h obtained over 16 000 h of testing. The voltage decay goal was achieved early in life for the other two stacks ($\approx$1500 h) while a decay of about −12 mV/1000 h was observed over 5000 test hours.

With this repeated and quite satisfactory performance, development emphasis was shifted to the non-repeating components associated with the larger size stacks required for the plant fuel cells modules. Four 152-cell stacks rated at 32 kW were constructed. Each of these stacks exhibiting prototypic characteristics of the module stacks was tested individually and in appropriately combined 64 and 96 kW configurations. The cell tech-

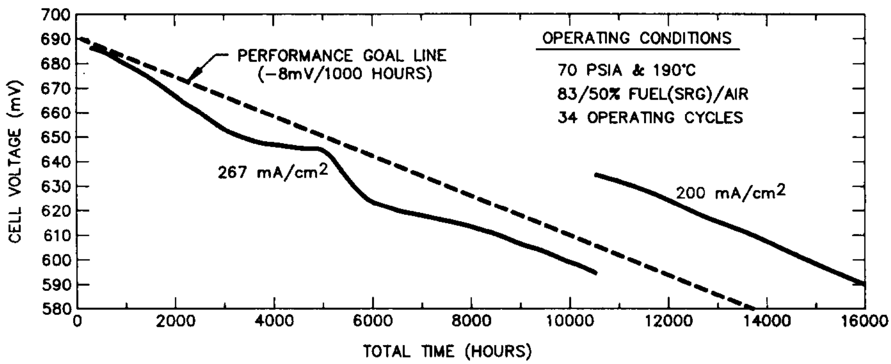

Fig. 5. Stack W010-22 performance stability.

TABLE 4

Large stack performance

Stack	Cell voltage (mV)
W152-01	694
W152-02	690
W152-03	688
W152-04	692

nology used in each of these stacks essentially duplicated that used in the earlier discussed ten cell stacks.

The beginning-of-life performance for each of these stacks is shown in Table 4. As shown, the beginning-of-life performance for each of these stacks nearly met or exceeded the 690 mV goal. The average performance for these stacks which represent over 600 individual cells is 691 mV. Furthermore, an average variance of 16 mV was achieved for some 100 six cell groups involved which represent the basic cell building block for stacks.

The performance decay for one of these stacks, namely Stack W152-04 is presented in Fig. 6. The overall voltage decay rate for this stack is 9.6 mV/1000 h. As shown, this rate of cell voltage loss was driven by an abnormally high rate of −23 mV/1000 h over the first 1500 h of testing.

This rate does not reflect the cell/stack technology but rather was incurred as a result of several unfortunate facility upsets and an operator error. This is supported by the achievement of 8.3 mV/1000 h voltage loss over the next 1500 h of testing.

In addition to having met or exceeded the initially established performance and technology scale-up goals, needed improvements in selected areas of the cell and stack were identified. The challenges to improve the performance included: a lower cell resistance; higher operating temperature; improved catalyst activity and design configuration; and process control improvements. To reduce the cell voltage loss involved: more corrosion

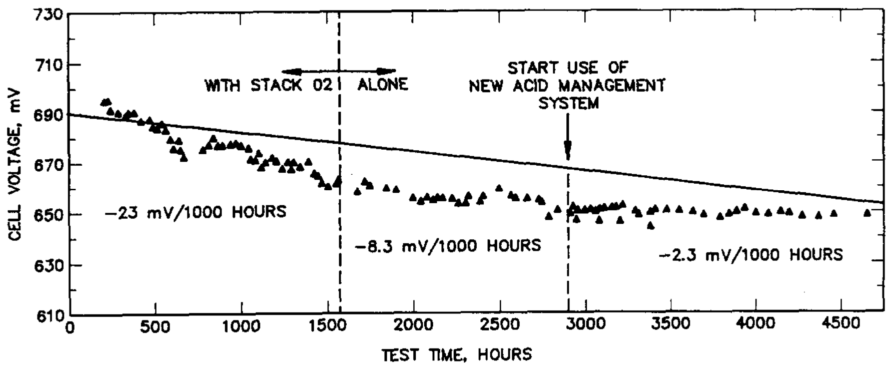

Fig. 6. Stack W152-04 performance stability.

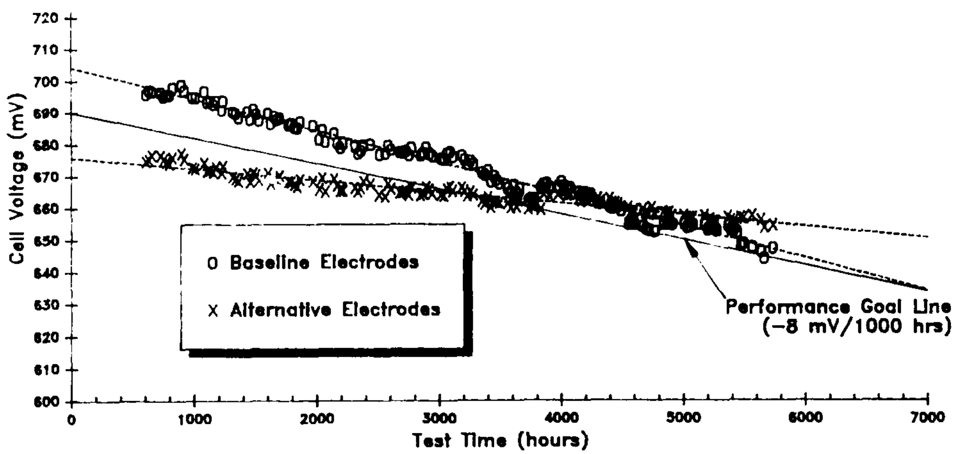

Fig. 7. Stack E010-09R.

resistant catalyst supports; a better electrolyte management system; and lower platinum or activity loss. Improving the module cost involved: single unit module stacks; improved matrix; electrode integral cell seal; and alternative electrode and plate manufacturing processes. During the past year, the thrust of the technical effort was directed towards pursuing the various solutions identified for each of these challenges.

After having completed appropriate screening tests, a more corrosion resistance catalyst support material was selected. A 10-cell stack was constructed which is comprised of five cathode electrodes containing an alternative catalyst carbon support and the balance the baseline support material. The performance of this stack is provided in Fig. 7. As shown, the performance stability of the alternative catalyst support cells is a factor of two less than the baseline cells, or −4.6 *versus* −10.9 mV per 1000 h. This improved voltage decay rate, however, is at the expense of a 21 mV loss in beginning-of-use performance or 698 *versus* 677 mV. The respective rates of voltage decay have been consistent for nearly 9000 test hours.

Another means of reducing the voltage decay rate involves an improved acid management system. This improved system was first used in 10-cell Stack W010-27 (Fig. 8) and then the 152-cell Stack W152-04 (Fig. 6). Similar encouraging results have since been demonstrated in 10-cell Stack W010-29 (Fig. 9) and the 100 kW Stack W446-01. As can be seen, the voltage decay rate was improved in each of these stacks to less than 4 mV/1000 h. This improvement was achieved using the baseline catalyst support material. In addition, Stack W010-29 contained a new matrix structure and configuration. The MAT-1 carbon layer was replaced with a vendor-supplied thin carbon layer.

Several efforts are underway to increase the beginning-of-use performance by 15–20 mV minimum. These include a thinner matrix, use of an alloy catalyst, higher platinum loadings and higher temperature operation. Initial test results indicate that a 25 mV improvement can be achieved [2, 3].

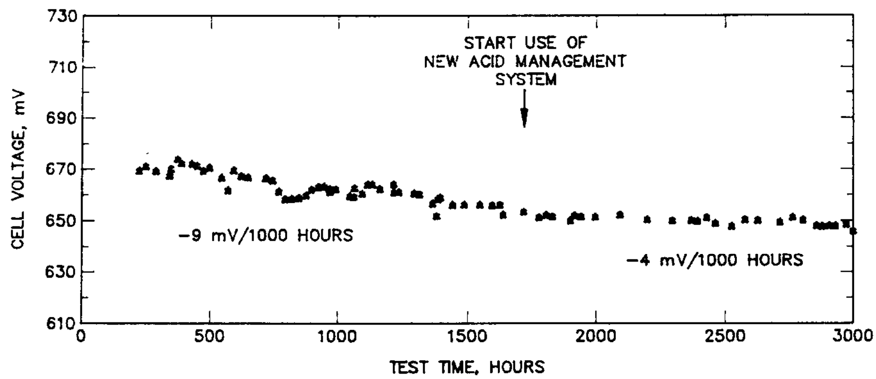

Fig. 8. Stack W010-27 affect on new acid management system.

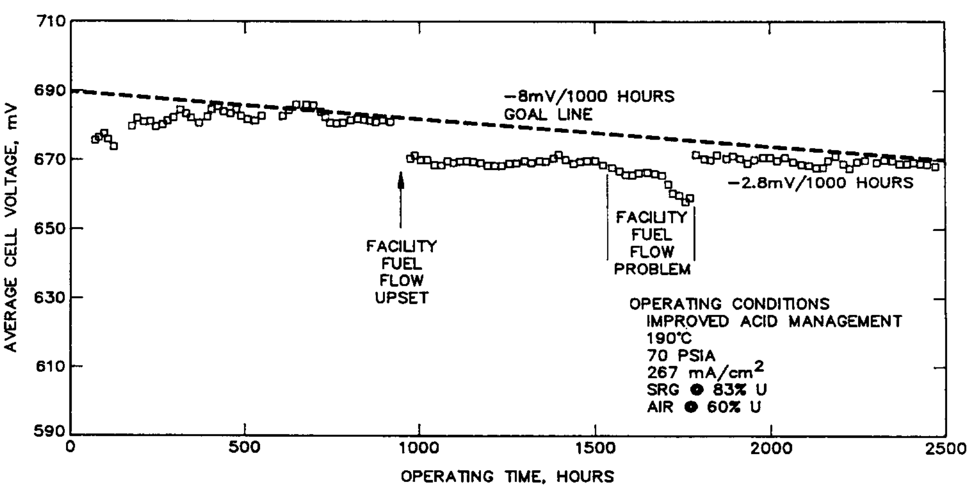

Fig. 9. Stack W010-29 performance stability.

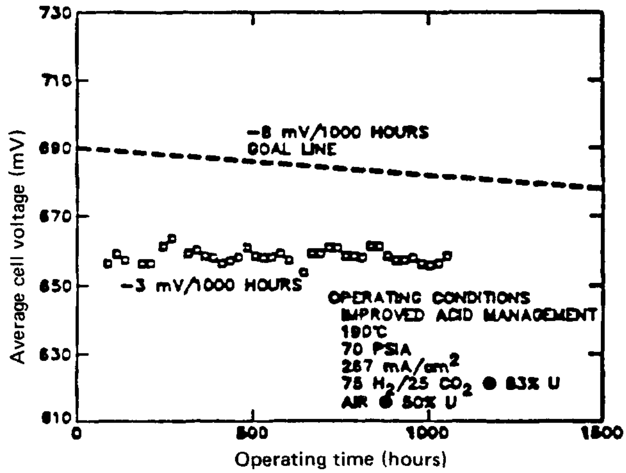

Fig. 10. Stack W446-01 performance stability.

Many areas are under investigation to meet the module cost objective of $2600/kW without employing mass production techniques. These encompass the cell materials, manufacturing processes and assembly methods as well as the cell/module design. The results of developments in several key areas are in the process of being finalized. These involve: (1) use of a thinner electrode support layer, (2) replacement of the MAT-1 carbon layer with a vendor-supplied product, and (3) integral electrode edge seal.

A most important element of our cost improvement plan involves the fabrication and testing of a single unit 446-cell stack. This stack is nominally rated at 100 kW. Its features are the most prototypic of the four stacks that will be used in the projects' end product, namely the 375 kW module.

The stack performance in all aspects was a notable success. The procedures, tooling and fixturing developed to assemble this single unit eight foot tall stack were all trouble-free. Perhaps, the most important achievement involves the leakage free performance of the process gasses' manifold seal joint. The overall voltage decay rate for this stack is less than 4 mV/1000 h for nearly 1600 h of operation, as shown in Fig. 10.

In summary, the technology is sufficiently in hand that proven solutions to the remaining challenges are being developed in a timely fashion. This in turn will thus allow their demonstration at the module level as planned.

References

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