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# Westinghouse Tubular SOFC Technology

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# WESTINGHOUSE TUBULAR SOFC TECHNOLOGY

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This paper presents an overview of the Westinghouse tubular Solid Oxide Fuel Cell (SOFC) Technology, current program status and realized progress in the field test programs. Activities which have followed the successful completion of the Multi-Kilowatt Generator (MKG) testing program are discussed herein. Advancements under this continuing program have resulted in the development of cells with greatly improved performance, reduced rate of degradation and increased life as well as the design, construction, and test of cell bundles and generator modules. Multiple single cell tests have now successfully exceeded 30,000 hours of power operation at temperature, and several generator tests have been successfully performed.

The ultimate objective of this project is to develop tubular solid oxide fuel cell (SOFC) technology to the point of acceptable risk for private sector commercialization. This objective involves the development of commercial market reference designs which, in turn, will define SOFC cost and performance criteria. The Cooperative Agreement with the U.S. Department of Energy is intended to advance the SOFC technology to the next phase of the ultimate objective. Cell technology, which meets cost and performance criteria, will be developed and demonstrated.

## BACKGROUND INFORMATION

Building upon prior year programs and accomplishments, in 1991 a Cooperative Agreement was initiated between Westinghouse and DOE-Morgantown Energy Technology Center (METC), covering a project period through November 1995. This ongoing program is focused on the continued development, improvement, and scale-up of the tubular SOFC for use with natural gas and coal-derived fuel gas.

Tubular SOFC technology is in the preliminary design stage of development and Westinghouse plans for field testing of multi-hundred kilowatt and multi-megawatt rated generators during the mid to latter-1990's.

## PROJECT DESCRIPTION

Successful commercialization of the SOFC technology during the 1990's depends on the ability to produce cost competitive systems that can operate for five to ten years before replacement of the SOFC module(s). A thorough understanding of the phenomena that limit cell and generator lifetime is required so that advanced processes and/or materials can be introduced. Furthermore, a detailed understanding of the manufacturing costs of cells and generators is also required in order to develop more cost effective processes and procedures.

The Westinghouse goal is to develop a cell that can operate for 50,000 to 100,000 hours. To date, Westinghouse has produced and operated for extended periods more than one thousand cells and has systematically improved cell performance, life, and voltage stability. Ongoing cell tests have surpassed 30,000 hours of operation with degradation rates in the range of 0.5 to 1.5% per 1,000 hours.

To enhance economic viability, Westinghouse is working to reduce the manufacturing costs of the cells and generators and to increase the power output per cell. Engineering studies indicate acceptability of the present cell diameter (approximately 1.5 cm), however, longer cells and increased power output per unit cell length contribute to improved power plant economics. Over the past few years Westinghouse has successfully increased the active length of the SOFC from 30 cm (in pre-1986 cells) to 100 cm (currently in production) with the a corresponding increase in power output per cell.

In parallel with increasing the cell length, Westinghouse also progressively reduced the thickness of the porous support tube (PST). Early technology SOFCs had a 2 mm thick PST (defined as a thick-wall PST) that provided the support structure for the SOFC. Although sufficiently porous to allow air flow to the air electrode, there was an inherent impedance to oxygen diffusion towards the active air electrode. Efforts were successful in first reducing the PST wall thickness to 1.2 mm (the thin-wall PST) and ultimately in eliminating the PST altogether. As the PST wall thickness was reduced and the PST eventually eliminated from the cell, the air electrode thickness was increased. The present technology SOFC's have an air electrode thickness that is sufficient to support the cell. The air electrode supported (AES) cell does not require the PST, thus reducing the impedance of oxygen diffusion toward the air electrode and further improving cell efficiency and power production. The combined effect of increasing the cell length from 30 cm to 100 cm and eliminating the PST, results in a six-fold increase in cell power output. Now in the initial stage of production are AES cells with a 100 cm active cell length. Application studies reveal that the 100 cm AES cells can satisfy a segment of the commercial market requirements in the 1990's and beyond, however, longer cells will further improve the economics, particularly for large central station electric utility power plants. The present development program is addressing the manufacture of longer cells.

Additional cost and performance benefits can be realized by the direct use of natural gas by the SOFC. This can be achieved by reforming the natural gas into hydrogen and carbon monoxide within the SOFC generator. Work sponsored by DOE, Westinghouse, and GRI has led to the concept of internal reforming. Through a unique fuel delivery system and exhaust gas recirculation, both developed by Westinghouse, the need for an external fuel reformer and an external steam source are eliminated. This reduces plant complexity and permits the energy that would normally be required to generate the reforming steam to be utilized in a more efficient manner. This key development goal was achieved in 1988/1989 with the successful demonstration of a 3 kW SOFC generator that operated directly on pipeline natural gas (PNG). The 3 kW SOFC generator was equipped with an internal reformer that reformed 75% of the incoming natural gas. The remaining 25% was reformed directly on the exterior surface of the SOFC's (the fuel electrode). The thermal energy and steam required for reforming the natural gas was supplied by the exhaust gas and by recirculation of a portion of the spent fuel, respectively. The 3 kW SOFC generator operated for more than 5,000 hours on pipeline natural gas.

A major step in the technology development program was the Westinghouse investment of capital funds to construct the Pre-Pilot Manufacturing Facility (PPMF). The 28,000 $ft^2$ PPMF is dedicated to SOFC manufacturing development. This facility provides the opportunity to move the SOFC technology from a laboratory environment to a manufacturing environment and enables the development of processes and quality control programs that are required for successful commercialization of the SOFC technology.

The PPMF has manufactured thousands of 50 cm thin-wall PST SOFCs in support of both the technology development program and the field test program (described in the following section of this report). The PPMF is presently in the process of manufacturing the latest generation of SOFCs, the 100 cm AES cell, and it is anticipated that even longer cells will be manufactured at the PPMF.

## RESULTS

Important to the development and commercialization of any new technology is a field test program. This is a mutually beneficial program for both the developer and the prospective user. The developer is able to acquire valuable field operating experience that is not available in a laboratory while the user has the opportunity to become familiar with the new technology and gains a working knowledge of it through hands-on operation. Westinghouse, recognizing these benefits, initiated such a program in 1986 by supplying a 400 W SOFC generator to the Tennessee Valley Authority (TVA). This generator operated for approximately 1,760 hours and was constructed of twenty-four 30 cm thick-wall PST cells.

In 1987, three, 3 kW SOFC generators were installed and operated at the facilities of the Tokyo Gas Company and the Osaka Gas Company. At Osaka Gas, two generators were used. The first, a training generator, operated for 2,900 hours before it was replaced on a preplanned schedule with the second generator. The second generator operated for 3,600 hours. The Tokyo Gas generator was operated for 4,900 hours. These generators had a 98% availability and measured NOx levels of less than 1.3 ppm. The 3 kW SOFC generators were constructed of 144, 36 cm thick-wall PST cells. The 3 kW generators, as was the TVA generator, were fueled with hydrogen and carbon monoxide.

The next major milestone in the field unit program was reached in early 1992 with the delivery to The UTILITIES, a consortium of The Kansai Electric Power Company, the Tokyo Gas Company, and the Osaka Gas Company, of a natural gas fueled all electric SOFC system. This system is rated at a nominal 25 kW dc with a peak capacity of 40 kW dc. The NOx was measured at <0.3 ppm (corrected to 15% oxygen). The system consists of 1,152 cells (thin-wall PST) of 50 cm active length, manufactured at the PPMF.

A second 25 kW SOFC system has been fabricated and is undergoing testing. This generator unit will produce ac power and intermediate pressure steam. This cogeneration system will be delivered to the Joint Gas Utilities (JGU), a cooperative effort between Tokyo Gas Company and Osaka Gas Company.

These Field Units represent practical incorporation of the lessons learned in the designing, manufacturing and operating of the MKG generator (20kW) at Westinghouse in Pittsburgh and demonstrate significant technology scale-up.

## SUMMARY

A summary of significant developments and accomplishments which have recently occurred throughout the tubular SOFC program include:

- Demonstration that thousands of tubular solid oxide fuel cells can be fabricated with consistent and reproducible performance.

- Continuous operation of a 3 kWe tubular SOFC system for over six months at a customer's test site.

- Demonstration of stable performance and lifetime in excess of 5,300 hours for a 3 kWe generator module, operating on desulfurized natural gas without external humidification.
- Demonstration of stable performance and life times in excess of 30,000 hours in multiple single cell tests.
- Design, construction and operation of a dedicated cell, module and generator Pre-Pilot Manufacturing Facility (PPMF).
- Successful 6,840 hour bundle tests of 50 cm. cells produced at the PPMF.
- Significant improvements in cell performance and life and marked reduction in cell degradation.
- Design, construction and successful operation of a 20 kWe tubular solid oxide fuel cell generator module.
- Design, construction, shipment and installation of 25 kWe (40 kWe peak power) field units.

## FUTURE WORK

The existing Cooperative Agreement between Westinghouse and the Department of Energy was initiated in April, 1991 and will continue through November 1995. This five year program includes considerable financial contributions from Westinghouse, from domestic and foreign utilities, and from other agencies, in addition to the U.S. Department of Energy. Under this program Westinghouse will continue development of the tubular solid oxide fuel cell technology and generator systems and plans for field testing of multi-hundred kilowatt and multi-megawatt rated generators during the mid to late-1990's, The ultimate objective of this program is to develop tubular SOFC technology to the point of acceptable risk for private sector commercialization.

Development of the tubular solid oxide fuel cell technology is being supported by the Westinghouse Electric Corporation, the United States Department of Energy (DOE), and various utility and industry sources. The Cooperative Agreement between Westinghouse and DOE is administered by the DOE-Morgantown Energy Technology Center (DOE-METC), Ms. Diane T. Hooie, Program Manager, Fuel Cells Branch. Funding for the evaluation of Westinghouse pressurized SOFC technology for utility applications in Japan is being supplied by a Japanese consortium composed of the New Energy and Industrial Technology Development Organization (NEDO), The Hokkaido Electric Power Company, The Tokyo Electric Power Company, The Chubu Electric Power Company, The Chugoku Electric Power Company, The Kyushu Electric Power Company and The Electric Power Development Company (EPDC).

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