# MCEN GRADUATE SEMINAR


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# Current Status of High Temperature Solid Oxide Fuel Cells

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**Abstract**

Solid oxide fuel cells (SOFCs) based on an oxide ion conducting electrolyte offer a clean, low-pollution technology to electrochemically generate electricity at high efficiencies. These cells operate between about 550 and 1000$^{o}$C, and some hydrocarbon fuels such as natural gas can be reformed within the cell stack eliminating the need for an expensive, external reformer. The most important need to commercialize SOFC technology is to significantly reduce the overall cost of SOFC-based power systems, while maintaining adequate performance and performance stability with time. Reduction of cell operation temperature enables use of low-cost metallic interconnects and a decrease in maintenance costs. However, at lower temperatures, greater ohmic loss due to reduced ionic conductivity of the electrolyte and reduced catalytic activity of the electrodes result in lower cell performance. To improve cell performance at lower temperatures, employing thin electrolyte and nanoscale materials in the electrodes has recently been considered. However, a crucial question that remains to be answered is whether the beneficial effect of employing nanoscale materials will persist even after long term cell operation at high temperatures, even though the initial performance may have indicated performance enhancement. This overview focuses on the materials, processing, and performance of solid oxide fuel cells, with relative advantages/disadvantages of tubular and planar geometries. Stacks and systems built with both tubular and planar geometries are described and their operating experience discussed. Applications of such cells in stationary, mobile and military market sectors are reviewed and challenges in reducing cell and system costs are summarized.


**Bio:**

Dr. Singhal joined the Energy and Environment Directorate at PNNL in April 2000 after having worked at Siemens Power Generation (formerly Westinghouse Electric Corporation) for over 29 years. At PNNL, Dr. Singhal provides senior technical, managerial, and commercialization leadership to the Laboratory's extensive fuel cell and clean energy programs. At Siemens/Westinghouse, he conducted and/or managed major research, development, and demonstration programs in the field of advanced materials for various energy conversion systems including steam and gas turbines, coal gasification, and fuel cells. From 1984 to 2000, he was manager of Fuel Cell Technology there, and was responsible for the development of high temperature solid oxide fuel cells (SOFCs) for stationary power generation. In this role, he led an internationally recognized group in the SOFC technology and brought this technology from a few-watt laboratory curiosity to fully-integrated 200 kW size power generation systems. He has authored 95 scientific publications, edited 17 books, received 13 patents, and given 305 plenary, keynote and other invited presentations worldwide.

Dr. Singhal is also an Adjunct Professor in the Department of Materials Science and Engineering at the University of Utah, and a Visiting Professor at the China University of Mining and Technology-

Beijing. He serves on the Advisory Boards of the Department of Materials Science and Engineering at the University of Florida, Florida Institute for Sustainable Energy, Division of Materials Science and Engineering at Boston University, Materials Research Science and Engineering Center at the University of Maryland, Center on Nanostructuring for Efficient Energy Conversion at Stanford University, and the Fuel Cell Institute at the National University of Malaysia.

Dr. Singhal is a member of the U.S. National Academy of Engineering and the Washington State Academy of Sciences; a Fellow of four professional societies (American Ceramic Society, The Electrochemical Society, ASM International, and American Association for the Advancement of Science); and a senior member of the Mineral, Metals & Materials Society (TMS). He served on the Electrochemical Society's Board of Directors during 1992-94, received its Outstanding Achievement Award in High Temperature Materials in 1994, and continues as the Chairman of its International Symposium on Solid Oxide Fuel Cells held biennially since 1989. He served as President of the International Society for Solid State Ionics during 2003-2005. He received the American Ceramic Society's Edward Orton Jr. Memorial Award in 2001; an Invited Professorship Award from the Japan Ministry of Science, Education and Culture in 2002; Christian Friedrich Schoenbein Gold Medal from the European Fuel Cell Forum in 2006; Fuel Cell Seminar Award for outstanding leadership and innovation in the promotion and advancement of fuel cell technology in 2007; and the prestigious Grove Medal in 2008 for sustained advances in fuel cell technology. He serves on the Editorial Board of the Elsevier's *Journal of Power Sources* and is an Associate Editor of ASME's *Journal of Fuel Cell Science and Technology*. He has also served on many national and international advisory panels including those of the National Materials Advisory Board of the National Research Council, National Science Foundation, Materials Properties Council, U.S. Department of Energy, NATO Advanced Study Institutes and NATO Science for Peace Programs, United Nations Development Program (UNDP), United Nations Industrial Development Organization (UNIDO), International Energy Agency (IEA), and the European Commission.