Polymer Electrolyte Fuel Cells Fabrication, Characterization and Mathematical Modelling

M. Secanell
Energy Systems Design Laboratory
Mechanical Engineering Department, University of Alberta

Zero-emission polymer electrolyte fuel cell vehicles, such as the Mercedes-Benz F-Cell, have demonstrated all the performance attributes that customers expect, such as long range, fast re-fuelling and cold start. However, fuel cells are still too costly to enable their successful commercialization. One of the major contributors to fuel cell costs is the platinum used inside the fuel cell electrodes. Fuel cells are highly efficient energy conversion devices that, when fuelled with hydrogen from either nuclear or renewable sources, are capable of providing continuous electrical power with zero emissions. Fuel cells are therefore being investigated as a replacement for the internal combustion engine in a variety of applications such as vehicles, remote power generators and combined heat and power applications. They are also an alternative to batteries in portable power applications such as laptops and cellphones due to their fast-recharging and long lifetime capabilities.

Experimental research has shown that functionally-graded and micro-structured electrodes present a great opportunity to reduce fuel cell platinum loading without negatively impacting performance thereby enabling widespread commercialization of this technology. However, novel techniques are necessary in order to fabricate, characterize and analyze such systems. Furthermore, fuel cell electrodes are only several micro-meters thick, making direct observation virtually impossible; therefore, mathematical models are also required to understand the physical processes occurring inside the electrode that limit fuel cell performance. Due to the challenges in each one of the aforementioned areas, and the multidisciplinary nature of fuel cell operation, an integrated analysis and design approach involving research in fabrication, characterization and mathematical modelling of fuel cells is necessary in order to further improve the current technology.

In this research seminar, an introduction to polymer electrolyte fuel cells will be provided, followed by an overview of the current research efforts being undertaken by our research group in electrode fabrication, characterization and mathematical modelling. A material inkjet printing technique for fabricating well-controlled fuel cell electrodes will be outlined, and results will be presented that demonstrate that electrodes fabricated using this methodology can achieve up to seven times higher catalyst utilization than conventional electrodes. Mass transport is a major barrier to effective catalyst utilization, therefore, a novel experimental setup and mathematical model to measure gas permeability, molecular and Knudsen diffusivity in porous electrodes will also be presented. Finally, in order to understand the physical processes taking place inside a fuel cell, a coupled membrane-electrode-assembly mathematical model that accounts for mass and charge transport will be described, as well as the multi-step electrochemical reaction kinetics occurring inside the electrode. The nonlinear mathematical model, solved using finite elements, will be used to analyze the experimental results obtained in our laboratory with inkjet printed electrodes.

In summary, an integrated approach to understanding fuel cells will be presented where fabrication, characterization and testing of fuel cells is closely linked to the development of new mathematical models for the design of improved, more commercial viable fuel cell electrodes.

Biography:

Dr. Marc Secanell is the director of the Energy Systems Design Laboratory and an assistant professor in the Department of Mechanical Engineering at the University of Alberta. His research area is in analysis and computational design of energy systems such as fuel cells and flywheels. His current research projects include the development of mathematical models for: a) multi-step electrochemical reactions, b) multi-component gas transport in porous media; and, c) multi-phase/reactive transport models for fuel cells. He is also actively working on the development of polymer electrolyte fuel cell electrode fabrication, characterization and testing methodologies. Before becoming an assistant professor, Dr. Secanell worked as an assistant research officer at the National Research Council Canada, Institute for Fuel Cell Innovation in Vancouver, Canada. He received his Ph.D. and M.Sc. in Mechanical Engineering from the University of Victoria (Canada) in 2007 and 2004 respectively. He holds a B.S. degree (2002) from the Universitat Politècnica de Catalunya (Barcelona, Spain) in Engineering with an emphasis on electrical machine design. He is an author of 22 journal publications and has presented his work at several national and international conferences. He was recently awarded the Association of Professional Engineers and Geoscientists of Alberta (APEGA) Early Accomplishment Award. Since his arrival at the University of Alberta, he has secured funding from government and industrial partners such as the Automotive Fuel Cell Cooperation Corp., Hydrogenics Corp. and Four Stones Inc.