Type of SOFC research is as follows:

1) Electrode preparation techniques to approach the ideal microstructure to minimize resistance losses and maximize electrochemical activity. These techniques have included polarized electrochemical vapour deposition and air brush spraying which we developed in our lab along with screen printing, modified dip coating and sol gel.

2) New anode materials to withstand hydrogen sulphide poisoning and, eventually, poisoning from other typical impurities such as ammonia, hydrogen chloride and other sulphur compounds. Initial testing is being done in hydrogen with 100 ppm and 0.5% hydrogen sulphide. This will be extended to methane with similar hydrogen sulphide concentrations to see if materials can be identified that can resist serious carbon deposition as well as sulphur poisoning. Several candidate materials (metals, oxides, sulphides, borides) have been identified based on considerations of electrical properties, thermal expansion coefficient and thermodynamic stability.

3) A more robust fuel cell involving metallic electrodes as opposed to metal-ceramic composites. Ferritic stainless steel which was micro-etched to provide as much three-phase interfacial area as possible has been tested as it has a comparable expansion coefficient to the stabilized zirconia electrolyte. However, overall electrochemical activity of the electrode is generally improved if it is a mixed electronic plus ionic conductor rather than solely electronic. Sufficient testing has not been done to evaluate this limitation.

CURRICULUM VITAE

Thomas Harvey Etsell

Birthplace: Toronto, Canada

Marital Status: Married, two children

Citizenship: Canadian

Business Address:
Department of Chemical and Materials Engineering
University of Alberta
Edmonton, Alberta T6G 2G6
Canada
Telephone: (780) 492-5594
Fax: (780) 492-2881
E-mail: tom.etsell@ualberta.ca

Home Address:
3508 – 117A Street
Edmonton, Alberta T6J 1V4
Telephone: (780) 434-7040

Education

1961 Honour Secondary School Graduation Diploma
York Mills Collegiate Institute, Toronto

1965 B.A.Sc. (Honours), Metallurgy and Materials Science
University of Toronto

1967 M.A.Sc., Ceramics
University of Toronto

1970 Ph.D. Chemical Metallurgy
University of Toronto

Graduate courses taken in physical chemistry of extractive metallurgy, inorganic chemistry, applied mathematics, solid state physics, computer science and German reading.

Employment

1960-65 Summer industrial experience (May - September) in the office, factory and laboratory at the Tremco Manufacturing Company in Toronto

1970 NATO Postdoctoral Fellow with Professor S. N. Flengas, University of Toronto (February - June)

1970-72 NATO Postdoctoral Fellow with Professor A. Klemm, Max-Planck-Institut fuer Chemie, Mainz, Germany

1972-75 Senior Research Associate with Professor C. B Alcock, University of Toronto

1975-81 Associate Professor of Metallurgical Engineering, University of Alberta, Edmonton

1976 Research Scientist (June – August), Algoma Steel Corporation, Sault Ste. Marie, Ontario

1981- Professor of Materials Engineering, University of Alberta, Edmonton

1993-94 Visiting Scientist, Ecole Nationale Supérieure de Chimie and Research Director, CNRS, Montpellier, France

Detailed Research and Industrial Experience

1960-65

Employment at the Tremco Manufacturing Company (a protective coatings industry) was quite varied and provided experience in many aspects of the operation of a secondary industry. Jobs included preparation of samples in the service department, general factory work in the packaging, shipping and receiving departments, manufacture of products in the roofing, varnish and paint departments, and quality control testing and trouble shooting in the laboratory.

1964-70
Undergraduate and graduate research encompassed several fields, chiefly high temperature electrochemistry, solid state chemistry and chemical metallurgy. Theses were supervised by Professor S. N. Flengas. B.A.Sc. thesis involved electrical conductivity measurements on oxide semiconductors. M.A.Sc thesis comprised a study of the preparation, electrical conductivities, transport numbers and applications of ceramic oxide electrolytes. Ph.D. thesis consisted of an investigation of: 1) the defect structure and electrical properties of refractory oxides and solid electrolytes, and 2) electrochemical kinetics and metallurgical applications of solid electrolyte cells. Reader and external examiner was Professor W. W. Smeltzer, Department of Materials Science and Engineering, McMaster University, Hamilton, Ontario L8S 4L7.

1970-72
Postdoctoral research in Germany predominantly involved an investigation of transport processes in molten salts and ionic compounds. Specifically, an experimental investigation of isotope effects on the electrical conductivity of lithium salts was pursued along with mathematical analyses of solid state reactions between binary oxides. A review paper was written on the ionic and electronic transport numbers in oxide mixed conductors.

1972-75
Research at the University of Toronto was devoted to the development of improved electrochemical sensors and new applications for them in process control in metallurgical industries. These goals led to many areas of basic and applied research including preparation, characterization, structure, electrochemistry and electrical properties of various glasses, ceramics and slags, analysis of glass-ceramic seals and deoxidation of liquid metals. These projects involved considerable interaction with ceramics and metals companies, mainly Quality Hermetics Limited (subsidiary of Leigh Instruments), Dofasco and Algoma Steel. Some of the studies were carried out at these industries and their facilities were used for analysis and testing. A new electrochemical probe for the continuous monitoring of dissolved oxygen in molten metals was developed.

1976
In the Metals Research Department at Algoma Steel, the electrochemical probe for continuous in-situ analysis of oxygen was modified for industrial use. Eight trials of the final prototype were made in the tundish of a bloom or beam concast machine. In all but one, the oxygen content was accurately monitored for the entire life of the tundish, generally several hours.

1975-
At the University of Alberta, research has centered around the preparation, electrical properties and applications of novel and established ceramic electrolytes, and extractive metallurgical processes for metals, chiefly secondary recovery.

Established electrolytes are predominantly stabilized zirconia, doped thoria and beta-alumina, while oxalate coprecipitation and a modified sol-gel process are generally being used to prepare other ionic materials, including solid solutions based on rare earth oxides as well as transition metal aluminates, ternary sulphates and doped oxide glasses. Applications focus on: 1) chemical sensors, e.g., a nonisothermal probe for continuous oxygen monitoring in liquid steel, sulphur sensor for stack and combustion gases, metal sensors for liquid metals, and environmental SO_2,

CO_2 and NO_x thin film sensors; and 2) solid oxide fuel cells, e.g., a new technique termed 'polarized electrochemical vapour deposition' has been developed to greatly expand the effective three-phase interfacial area at the electrodes, thereby lowering the operating temperature. In addition to electrode microstructure, anode materials tolerant to sulphur poisoning and natural gas (resist carbon deposition), and more robust cells with alloy electrodes are also being studied. Further solid electrolyte applications include determination of thermodynamic properties of refractory carbides and transition metal sulphides.

Related research in high temperature physical chemistry and ceramic materials includes thermogravimetric analysis of defects in ceramics and of gas-solid reactions, kinetics of coal and oil sands coke gasification, and preparation, characterization and applications of oxide ceramic-metal composites. Companies such as Stelco, Leeds and Northrup, Electronite and Cominco have been involved in various aspects of this work.

Projects have been carried out in non-ferrous extractive metallurgy involving the hydrometallurgical recovery of molybdenum from phosphate rock, precious metals from black sand and placer deposits, and nickel from arsenic-bearing ores. More recently, secondary recovery has been emphasized, namely vanadium and byproduct metals (Ni, Mo, Ti) from oil sands fly ash, heavy minerals from oil sands tailings, silver from photographic films and solutions, and lead from scrap storage batteries. Processes for vanadium and lead have reached the pilot plant stage (Vadnore Enterprises, Ltd. and Wildrose Recycling, respectively), while silver recovery from fixer and bleach solutions has been commercialized (Photochemical Recycling, Inc.).

In an effort to extract valuable metals and/or sequester toxic ones in industrial waste materials, a protocol for transformational roasting (whereby the mineral matrix is altered) has been developed. To date, it has been applied to oil sands fly ash, zinc ferrite residues, electric arc furnace steelmaking dust and a copper-nickel-arsenic sulphide waste.

<u>1993-94</u>

In France, research involved preparation (sol-gel) and characterization (high resolution SEM, BET adsorption, IR spectroscopy) of ceramic membranes (stabilized zirconia) for gas separation. Separation usually relies on the pore structure of the membranes. Efforts were made to produce dense membranes that realized separation of oxygen by $O^{=}$ ion conduction through the membrane. Oxygen ions were generated and consumed via electrode reactions at the membrane/gas interfaces. Use of mixed conducting membranes (partially stabilized zirconia or CeO_2) would eliminate the need for electrodes. Electrical properties of membranes deposited on alumina support tubes were determined via two-probe and four-probe impedance measurements from 1010 Hz at 350-700°C.

Teaching Experience

<u>1966-69</u>

While a graduate student I taught undergraduate courses in thermodynamics, electrochemistry and differential equations.

<u>1975-</u>

At the University of Alberta I have taught a variety of lecture, project, research and design courses:

Undergraduate	**Graduate**
Materials Science	Advanced Ceramics
Pyrometallurgy	Electrochemical Processes
Hydrometallurgy and Electrometallurgy	Process Metallurgy
Thermodynamics and Kinetics	High Temperature Oxidation
Ceramics	Advanced Materials Thermodynamics
Metallurgical Plant Design and Operation	
Materials Process Engineering Design	
Special Topics in Materials Engineering	
Materials Research Project	

Initiatives

Have introduced four new undergraduate and two new graduate courses. Have introduced new labs for three undergraduate courses.

Instruct graduate students on becoming effective teaching assistants.

Developed occupational profiles of a Ceramic Engineer and Materials Engineer for Alberta Advanced Education and Career Development.

Helped prepare a set of videos supported by written material for use Canada-wide describing educational opportunities in six areas of advanced technology as a member of a Focus Group, Centre for Career Development Innovation, Concordia College.

Research Interests

Research centres around:

1. Properties and applications of mixed and ionically conducting ceramics, and of ceramic-metal composites
2. Extractive metallurgy to recover metals and minerals from both primary and secondary sources.

Ceramics

Structure and electrical and transport properties of a variety of ionic and mixed conductors including stabilized zirconia, doped thoria, rare earth oxide-based systems, β-alumina, ternary sulphates and transition metal aluminates. Applications focus on sensors for the steel industry, gas sensors for process and pollution control, and solid oxide fuel cells. Fuel cell work centres around anode microstructure, materials and interactions with fuel impurities. Also, fuel production by coal and coke gasification.

Extractive Metallurgy

Hydro- and pyrometallurgical recovery of metals from primary sources, e.g., nickel from arsenious ores, molybdenum from phosphate rock, platinum and palladium from black sands and placer deposits, and from secondary sources, e.g., heavy metals from oil sands fly ash, lead from scrap auto batteries, silver from photographic materials. Patents have been issued for the last three. Transformational roasting to enhance metal recovery from and disposability of industrial waste materials.

Recent Research Grants

Years	Funding Agency	Title	Amount/Year
1999-01	NSERC Strategic	Development of Novel Porous Composite Electrodes and their Impact on the Performance of Solid Oxide Fuel Cells	$85,300
2000-03	COURSE	Impact of Residual Bitumen Removal Methods on the Separation of Heavy Minerals in the Oil Sands Tailings	$37,000
2001-02	MSTRI	Novel Solid Oxide Fuel Cell Proof of Concept	$75,000
2001-02	NSERC Equipment	Electrochemical Impedance Analyzer	$36,725
2001-02	NSERC Equipment	Atomic Absorption Spectrometer	$48,460
2001-06	NSERC Discovery	Ceramic Electrolytes and Secondary Recovery	$36,000
2003-05	COURSE	Multi-Scale Modelling of Solid Oxide Fuel Cells	$106,258
2003-05	COURSE	Production of Hydrogen and Nanocarbons from Light Hydrocarbons Contained in Alberta Coal	$97,920
2003-06	NSERC Strategic	Hydrogen Sulfide Compatible Solid Oxide Fuel Cell	$103,333
2004-05	NSERC Equipment	Micro GC TCD Interface for Integration of Existing Pyrolysis, Combustion and Catalyst Research	$91,765
2005-06	AERI/WEPA	Development of High Temperature Fuel Cell Systems for Alberta	$88,750
2005-08	OSTRF	Mineralogy of Oil Sands Solids Using High Resolution TEM	$27,500

Supervision

<u>Present</u>

Currently supervise one M.Sc. student, four Ph.D. students, two research associates, one research assistant and two WISEST students.

Past Six Years

Excluding the above, have supervised six M.Sc. students, two Ph.D. students, eight research assistants and three WISEST students.

Scholarships and Fellowships

1961	J. P. Bickell Memorial Scholarship
1963	American Society for Metals Scholarship
1965	Ford Foundation Fellowship
1966, 1967	NRC Studentship
1968	NRC Postgraduate Scholarship
1969, 1970	NATO Postdoctoral Fellowship

Awards

1971	Best Paper Award (Electrochemical Society)
1984, 1987, 2002	Engineering Undergraduate Teaching Award
1997	Best Paper Award (Microscopical Society)
1998	Two Best Paper Awards (CIM)
1999	Altamet Resource Recovery, Inc., a U of A spin-off company, was formed to initially commercialize our process for recovering vanadium from oil sands fly ash.
2000	Design Award (gold medal, equipment category) for Photochemical Recycling Technology (Internat. Design Annual Design Review 47 (5), 176-77 (2000))

Professional Affiliations

- APEGGA
- Canadian Institute of Mining, Metallurgy and Petroleum (CIM)
- The Minerals, Metals and Materials Society (TMS)

Advisory Boards

- Materials Science Foundations, Trans Tech Publications Ltd., Switzerland
- University of Alberta Advanced Engineering Materials Center

Selected External Offices Held

1976-81	Executive Committee, Edmonton Chapter, American Society for Metals
1982-83	Organizing Committee, 22nd Annual Conference of Metallurgists, Edmonton

1990-92	Organizing Committee, 8th International Conference on Solid State Ionics, Lake Louise, Alberta
1990-	Proposal Review Committee, Alberta Research Council Joint Research Venture Assessment
1991-95	Focus Group, Centre for Career Development Innovation, Concordia College
2000-	Organizing Committee, Canadian Fuel Cell Systems Symposia, Edmonton, May 24-25, 2001, Calgary, February 26-28, 2003, Banff, October 12-14, 2005
2002-	Western Canada Fuel Cell Initiative Steering Committee

Selected University Offices Held

1986-89/97-00	ECC
1987-91	Faculty of Graduate Studies and Research Scholarship Committee
1995-98	Faculty of Engineering Publicity and Awards Committee
2000-03	Chair, Faculty of Engineering Academic Appeals Committee
2002-05	Associate Chair, Materials Engineering

References

Professor A. Petric
Department of Materials Science and Engineering
McMaster University
Hamilton ON L8S 4L7
Canada

Dr. J. M. Skeaff
Minerals Technology Branch
Natural Resources Canada
555 Booth Street
Ottawa ON K1A 0G1
Canada

Professor A. McLean
Department of Metallurgy and Materials Science
University of Toronto
Toronto ON M5S 3E4
Canada

Professor M. L. Wayman
Department of Chemical and Materials Engineering
University of Alberta
Edmonton AB T6G 2G6
Canada

Professor A. Klemm
Max-Planck Institut fuer Chemie
Saarstrasse 23
55122 Mainz
Germany

Professor R. I. L. Guthrie
Department of Mining and Metallurgical Engineering
McGill University
Montreal PQ H3A 2B2
Canada

Professor M. S. Whittingham
Materials Research Center
State University of New York
Binghamton NY 13902
USA

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