CURRICULUM VITAE

Thomas Harvey Etsell

Birthplace: Toronto, Canada

Marital Status: Married, two children

Citizenship: Canadian

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Education

1970 Ph.D. Chemical Metallurgy
University of Toronto
Thesis: "The Electrical Properties of La_2O_3-CaO, Y_2O_3-CaO, and ZrO_2-CaO Solid Electrolytes"
Supervisor: S. N. Flengas

1967 M.A.Sc., Ceramics
University of Toronto
Thesis: "Electrical Conductivity Measurements on La_2O_3- CaO Solid Oxide Electrolytes"
Supervisor: S. N. Flengas

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

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

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

Employment

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

2012-13 Visiting Scientist, University of Toronto and University of Zaragoza, Spain

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

1976 Research Scientist (June – August), Essar Steel Algoma Inc., Sault Ste. Marie, ON

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

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

1970-72 NATO Postdoctoral Fellow with Professor A. Klemm, Max-Planck-Institut fuer Chemie, Mainz, Germany (July 1970 – May 1972)

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

1960-65 Summer industrial experience (May – September) as a factory worker, lab assistant and department head in the office, factory and laboratory at the Tremco Manufacturing Company in Toronto

Detailed Research and Industrial Experience

2012-13

At the University of Toronto, helped undergraduate and graduate students working on metal-supported planar fuel cells via individual discussions and group meetings. Problems included fabrication of the stainless steel metal supports, ceramic coatings to protect them from oxidation and chromium diffusion, and integrity of electrode and electrolyte layers applied by thermal spraying. At the University of Zaragoza in Spain, expanded my knowledge of extrusion, the ceramic processing technique that is an alternative to slip casting to fabricate fuel cells. Although extrusion is perhaps being better suited to mass production, slip casting offers easier modifications for research purposes. We have recently completed designing and building a lab-scale extruder. This collaboration continues.

1993-94

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 $10^{-3}-10^{5}$ Hz at 350-700°C.

. **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.

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.

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.

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

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.

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.

Teaching Experience

1975-

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	
Processing and Applications of Ceramics	
Applied Electrochemistry	
Extractive Metallurgy	

1966-69

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

Philosophy

I have made almost all of the courses I have taught problem-oriented. Developing analytical skills for problem solving is a very important skill for engineers. I give out comprehensive problem sets, do many example problems during lectures and have always made midterms and final exams at least 50% quantitative.

Most of these courses have had an associated lab. Again the labs are quantitative with lots of calculations and attention to careful experimentation to obtain meaningful results. Generally I have a lab exam focused entirely on these calculations near the end of the term.

Initiatives

In two recent courses (Applied Electrochemistry and Extractive Metallurgy) I developed an extensive set of examples problems to be used in associated seminars that I run myself.

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.

Teaching Experience and Evaluations

Course	Description	Term	Enrol-ment	USRI median*
MAT E 202	Materials Science II	Winter 2017	90	4.4
MAT E 471	Ceramics	Winter 2017	13	4.8
MAT E 680	Advanced Ceramics	Winter 2017	8	4.8
CME 472	Extractive Metallurgy	Winter 2016	23	4.6
MAT E 202	Materials Science II	Winter 2016	110	4.6
MAT E 202	Materials Science II	Summer 2015	111	4.2
CME 483	Colloquium II	Winter 2015	22	4.8
MAT E 471	Ceramics	Winter 2015	27	4.3
MAT E 680	Advanced Ceramics	Winter 2015	6	4.3
MAT E 202	Materials Science II	Summer 2014	75	4.8
CME 472	Extractive Metallurgy	Winter 2014	18	4.9
MAT E 471	Ceramics	Winter 2014	21	5.0
MAT E 202	Materials Science II	Summer 2012	73	4.5
CME 472	Extractive Metallurgy	Winter 2012	8	4.9
MAT E 471	Ceramics	Winter 2012	26	4.9
MAT E 738	Process Metallurgy	Winter 2012	4	4.9
MAT E 202	Materials Science II	Summer 2011	72	4.0
CME 472	Extractive Metallurgy	Winter 2011	11	4.9
MAT E 341	Applied Electrochemistry	Winter 2011	50	4.9
MAT E 738	Process Metallurgy	Winter 2011	3	4.9
CME 472	Extractive Metallurgy	Winter 2010	11	5.0

MAT E 341	Applied Electrochemistry	Winter 2010	46	4.8
MAT E 471	Ceramics	Fall 2009	18	4.5
CME 472	Extractive Metallurgy	Winter 2009	13	4.5
MAT E 430	Hydrometallurgy and Electrometallurgy	Fall 2008	23	4.7
MAT E 471	Ceramics	Fall 2008	27	4.7
CME 481	Colloquium I	Winter 2008	20	4.9
MAT E 332	Pyrometallurgy	Winter 2008	29	4.8
MAT E 430	Hydrometallurgy and Electrometallurgy	Fall 2007	33	4.6
MAT E 471	Ceramics	Fall 2007	32	4.8
MAT E 332	Pyrometallurgy	Winter 2007	31	4.7
MAT E 680	Advanced Ceramics	Winter 2007	7	
MAT E 480	Ceramics	Fall 2006	32	4.7
MAT E 332	Pyrometallurgy	Winter 2006	27	4.7
MAT E 430	Hydrometallurgy and Electrometallurgy	Fall 2005	23	4.6
MAT E 480	Ceramics	Fall 2005	27	4.7
MAT E 332	Pyrometallurgy	Winter 2005	25	4.4
MAT E 481	Processing and Applications of Ceramics	Winter 2005	13	
MAT E 480	Ceramics	Fall 2004	23	4.9

* The course rating system at the University of Alberta ranks responses to the USRI question 221 “Overall, this instructor was excellent” on a scale of 1 – 5, with 1 being “strongly disagree” and 5 being “strongly agree”

Supervision of Graduate Students and Postdoctoral Fellows

Name	Year Admitted	Year Graduated	Degree	% Supervision /Joint with	Present Position
Michael Moore	2017		PhD	50%/M. Secanell	Enrolled full time, U of A
Sajad Vafeenezhad	2017		PhD	50%/J. Luo	Enrolled full time, U of A
Taghi Amiri	2015		PhD	50%/J. Luo	Enrolled full time, U of A
Mirjavad Geramian	2014		PhD	33%/Q. Liu, D. Ivey	Enrolled full time, U of A
Jared Deutsch	2012	2015	PhD	50%/H. Askari-Nasa	Newmont Mining, Nevada
Ali Torabi	2007	2012	PhD	100%	FuelCell Energy, DanburyCT
Ali Hooshiar	2006	2011	PhD	33%/Q. Liu, D. Ivey	SRK Consultants, Vancouver
Patrick Kerr	2005		PhD	50%/Q. Liu	Minepromet, Quebec City
Preston Holloway	2003	2006	PhD	100%	Dynatec, Fort Saskatchewan
Heather Kaminsky	2003	2008	PhD	50%/D. Ivey	Suncor Energy, Calgary
Roy Ifill	2000	2010	PhD	100%	SET Foundation, Calgary
Craig Eastman	2000	2006	PhD	100%	Principle Energy, Edmonton
Farhad Azam	2012		MSc	33%/Q. Liu, D. Ivey	Enrolled part time, U of A
Limin Zheng	2011	2013	MSc	33%/Q. Liu, D. Ivey	Pentair Thermal, Edmonton
Stephen Gibson	2009	2012	MSc	100%	Corrpro, Edmonton
Alex Lu	2003	2006	MSc	50%/Z. Xu	Returned to PR China
Christine Volohatuke	2002	2005	MSc	100%	Acuren Group, Edmonton
Heemun Jang	2001	2004	MSc	100%	Teck Cominco, Vancouver
Mark Haldane	2001	2004	MSc	100%	NRC-IFCI, Vancouver
Preston Holloway	2000	2002	MSc	100%	Dynatec, Fort Sasketchewan
Zhangming Cui	1999	2003	MSc	50%/Q. Liu	Cosyn Technology
Sabereh Rezaei	2015	2016	PDF	100%	PDF, University of Toronto
Igor Stricek	2015	2016	PDF	33%/Q. Liu, D. Ivey	Returned to Czech Republic
Mehdi Alipour	2015	2015	PDF	100%	PDF, University of Alberta
Bin Hua	2014		PDF	50%/J. Luo	PDF, University of Alberta
Cheng Wang	2013	2015	PDF	33%/Q. Liu, D. Ivey	Returned to PR China

Ali Torabi	2012	2012	PDF	100%	FuelCell Energy, DanburyCT
Marek Osacky	2011	2012	PDF	33%/Q. Liu, D. Ivey	Comenius Univ., Bratislava
Amir Hanifi	2009	2014	PDF	100%	Research Associate, U of A
Arek Derkowski	2009	2010	PDF	33%/Q. Liu, D. Ivey	Chevron, Houston
Peter Uhlik	2007	2009	PDF	33%/Q. Liu, D. Ivey	Comenius Univ., Bratislava
Craig Eastman	2006	2007	PDF	100%	Principle Energy, Edmonton
Reza Naghash	2005	2007	PDF	100%	Rio Tinto, Labrador

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.

<u>Ceramics</u>

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.

<u>Extractive Metallurgy</u>

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

Current Research Support

Years	Funding Agency	Title (Principal and Co-Investigators)	Amount/Year
2017-24	Government of Canada (Future Energy Systems)	High Temperature Electrolysis for Energy Storage (T. Etsell, PI, J. Luo)	$72,000
2017-17	InnoTech Alberta	Surface Characterization and Chemical Analysis (T. Etsell)	$7,000
2016-21	NSERC Discovery	Tubular Solid Oxide Fuel Cells (T. Etsell)	$33,000

Past Research Support

2015-16	NSERC Research Tools & Instruments	Probing Intermolecular Inter-actions and Mapping Properties by AFM (H. Zeng, PI, 8 others)	$150,000
2014-16	CCEMC	Novel Internal Dry Reforming SOFC Technology for CO_2 Utilization (J. Luo, PI, T. Etsell, PI, P. Sarkar)	$250,000
2013-16	NRCan/Imperial Oil Ltd.	Fundamentals of Non-Aqueous Extraction of Oil Sands (T. Etsell, PI, Q. Liu, D. Ivey)	$212,000
2011-16	NSERC Discovery	Ceramic Electrolytes and Secondary Recovery (T. Etsell)	$30,000
2013-13	Alberta Innovates – Technol.Futures	Feasibility Studies of Reversible SOFCs for Electrical Energy Storage (T. Etsell)	$7,500
2011-11	NSERC Engage	Clear Hills Ironstone Beneficiation (Q. Liu, PI, T. Etsell)	$80,000

2010-12	COSI	Nano and Microsize Minerals in Non-Aqueous Bitumen Extraction from Oil Sands (T. Etsell, PI, Q. Liu, D. Ivey)	$194, 683
2008-13	NSERC Strategic Network	Porous Electrolyte-Supported Tubular SOFC System (T. Etsell)	$66,000
2008-09	NSERC Research Tools & Instrument	Hot Isostatic Press (D. Li, PI, W. Chen, T. Etsell, H. Henein, J. Luo, L. Unsworth)	$136,795
2007-10	COSI	Clay Mineralogy in the Oil Sands (T. Etsell, PI, Q. Liu, D. Ivey)	$129,107
2006-11	NSERC Discovery	Ceramic Electrolytes and Secondary Recovery (T. Etsell)	$34,000
2005-08	OSTRF	Mineralogy of Oil Sands Solids Using High Resolution TEM (D. Ivey, PI, T. Etsell)	$27,500
2005-06	AERI/WEPA	Development of High Temperature Fuel Cell Systems for Alberta (T. Etsell, PI, A. Nelson)	$88,750
2004-05	NSERC Equipment	Micro GC TCD Interface for Integration of Existing Pyrolysis, Combustion and Catalyst Research (Z. Xu, PI, T. Etsell)	$91,765
2003-06	NSERC Strategic	Hydrogen Sulfide Compatible Solid Oxide Fuel Cell (T. Etsell, PI, A. Nelson)	$103,333
2003-05	COURSE	Production of Hydrogen and Nanocarbons from Light Hydrocarbons Contained in Alberta Coal (Z. Xu, PI, T. Etsell)	$97,920
2003-05	COURSE	Multi-Scale Modelling of Solid Oxide Fuel Cells (S. Meadows, PI, T. Etsell, A. Nelson)	$106,258
2001-06	NSERC Discovery	Ceramic Electrolytes and Secondary Recovery (T. Etsell)	$36,000
2001-02	NSERC Equipment	Atomic Absorption Spectrometer (Z. Xu, PI, T. Etsell, Q. Liu)	$48,460
2001-02	NSERC Equipment	Electrochemical Impedance Analyzer (T. Etsell)	$36,725
2001-02	MSTRI	Novel Solid Oxide Fuel Cell Proof of Concept (T. Etsell)	$75,000
2000-03	COURSE	Impact of Residual Bitumen Removal Methods on the Separation of Heavy Minerals in the Oil Sands Tailings (Q. Liu, PI, T. Etsell)	$37,000

Scholarships and Fellowships

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

Awards

2010	Billiton Gold Medal (Institute of Materials, Minerals and Mining, London)
2008	Two Best Paper Awards (Clay Minerals Society, CIM)
2008	21st Canadian Materials Chemistry Award
2001, 2002	Rutherford Teaching Award nominee
2000	Design Award (gold medal, equipment category) for Photochemical Recycling Technology (Internat. Design Annual Design Review 47 (5), 176-77 (2000))
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.
1998	Two Best Paper Awards (CIM)
1997	Best Paper Award (Microscopical Society)
1984, 1987, 2002	Engineering Undergraduate Teaching Award
1971	Best Paper Award (Electrochemical Society)

Professional Affiliations

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

Advisory Boards

- Hydrogen and Fuel Cells, De Gruyter Open Ltd., Warsaw
- Materials Science Foundations, Trans Tech Publications Ltd., Switzerland
- University of Alberta Advanced Engineering Materials Center

Editorial Boards

- Waste and Biomass Valorization, Springer-Verlag, Berlin
- Internat. J. of Innovative Materials and Processing Technology, Elsevier, Amsterdam

Panels

- Fuel Cell and Energy Technology, British Columbia Innovation Council, Vancouver
- Hydrogen Fuel Cell, Ontario-China Research and Innovation Fund, Toronto

Selected External Offices Held

2007-08	Co-chair, 20th Canadian Materials Science Conference, Edmonton
2002-	Western Canada Fuel Cell Initiative Steering Committee
2000-	Organizing Committee, Canadian Fuel Cell Systems Symposia, Edmonton, May 24-25, 2001, Calgary, February 26-28, 2003, Banff, October 12-14, 2005
1991-95	Focus Group, Centre for Career Development Innovation, Concordia College
1990-	Proposal Review Committee, Alberta Research Council Joint Research Venture Assessment
1990-92	Organizing Committee, 8th International Conference on Solid State Ionics, Lake Louise, Alberta
1982-83	Organizing Committee, 22nd Annual Conference of Metallurgists, Edmonton
1976-81	Executive Committee, Edmonton Chapter, American Society for Metals

Selected University Offices Held

2013-	University Academic Appeals Committee
2002-05	Associate Chair, Materials Engineering
2000-03	Chair, Faculty of Engineering Academic Appeals Committee
1995-98	Faculty of Engineering Publicity and Awards Committee
1987-91	Faculty of Graduate Studies and Research Scholarship Committee
1986-89/97-00	Executive Coordinating Committee

Research Contributions

My main area of research is electrical properties and applications of ionically and mixed conducting ceramic materials. Applications have focused on electrochemical sensors and high temperature fuel cells. Although the conditions are severe, these sensors can give in situ chemical analyses in liquid metals or furnace atmospheres during industrial operations, e.g., steelmaking, heat treating. Results relate to the actual process conditions as opposed to taking samples to a lab where reactions during cooling change the composition in often unpredictable ways. Objectives have been to improve the accuracy (a101, a110, c38) and lower the response time (a85, a97, c22) of existing sensors. Accomplishments have included the development of a continuous rather than single reading sensor for liquid steel (a104, a105, c34, c37) and novel sensors for both gases (a62, a84, c24) and liquid metals (a102, c28, c37).

High temperature or solid oxide fuel cells have the important advantage of fuel versatility but must withstand a high operating temperature (~800°C) for extended periods. Fabricating them is a serious problem and they are prone to cracking on thermal and redox cycling (the latter occurs when oxygen enters the fuel electrode compartment due to leaks, maintenance or an interruption in the fuel supply). Although offering less power per unit volume, we are focused on the tubular design as high temperature sealing problems are minimized. Long term objectives are developing a reliable fabrication process that gives robust cells and identification of new anode materials that can withstand sulphur impurities in the fuel and prevent carbon deposition when using CO or CH_4. Major accomplishments have been to develop novel fabrication techniques (a2, a5, a11, a20, a22, a32, a34 a44, a47, a87, a99, c5) and recently producing a robust cell that gives high power density (a21, a24, a46, a48). New anode materials have been identified and studied (a6, a10, a14, a25, a37, a38, a39, c35, c36). Recently, novel uses have been investigated including CO_2 utilization via dry reforming of methane whereby the fuel cell and reforming reactions are both chemical and thermally coupled (a10, a14) or thermally coupled only (unpublished).

My second area is the primary and secondary recovery of metals and minerals with a strong focus on secondary recovery, i.e., recovery from waste products, residues, ash, by-products, etc. The objective is to develop relatively environmentally friendly processes that allow industry to recover valuable metals or metal compounds from waste products and/or tie up toxic ones for safe disposal. Initially, work involved recovery of vanadium from oil sands fly ash (a68, c29, c31, e7), silver from a variety of sources (a73, a78, c25, c26, c27, e4, e5) and lead from auto batteries (e3). The processes for vanadium and lead led to pilot plant studies while the one for silver from photographic materials was commercialized. Recently, we have developed transformational roasting whereby additives are added to waste products prior to heating them in air to effect mineralogical changes to liberate valuable metals or sequester toxic ones. To date, La Oroya zinc ferrite waste (a53, a55), Altasteel electric arc furnace steelmaking dust (a56, a58) and Inco nickel-copper residue (unpublished as yet) have been used to test the procedure (a52). Recently, a process has been studied to upgrade iron from a massive but complex deposit in the Peace River district in Alberta (c1, c3).

A third related area involves characterization of clays and other micro and nano sized minerals in the Alberta oil sands. The objectives are to develop a better understanding of the clay and sand layers that comprise the oil sands deposit and of the influence of clay and other minerals, chiefly iron minerals, on both aqueous and non-aqueous processing. Accomplishments to date include identifying how clay and iron minerals distribute themselves during aqueous processing (a50, a51, a64, c9, c10, c12), and developing a non-aqueous bitumen extraction process (a42, c8) to appreciate how clays may behave in this scenario (a1, a8, a17, a23, a30, a41, c7).

Publications – Refereed Journals

(a1) M. Osacky, **M. Geramian**, P. Uhlik, **M. Caplovicova**, **Z. Dankova**, **H. Palkova**, **M. Vitkova**, **M. Kovacova**, D. G. Ivey, Q. Liu and T. H. Etsell, 2017, "Mineralogy and Surface Chemistry of Alberta Oil Sands: Relevance to Non-Aqueous Solvent Bitumen Extraction", *Energy and Fuels*, **31**, 8910-24.

(a2) Amir R. Hanifi, Navjot K. Sandhu, Thomas H. Etsell and Partha Sarkar, 2017, "Development of a Novel Proton Conducting Fuel Cell Based on a Ni-YSZ Support", *J. Am. Ceram. Soc*., 2017;00:1-5. https://doi.org/10.1111/jace.15084

(a3) **A. Ghotbi Varzeneh**, **P. Kameli**, **T. Amiri**, **K. K. Ramachandran**, A. Mar, **I. Abdolhosseini Sarsari**, J. L.Luo, T. H. Etsell and H. Salamati, 2017, "Effect of Cu Substitution on Magnetocaloric and Critical Behavior in $Ni_{47}Mn_{40}Sn_{13-x}Cu_x$ Alloys", *J. Alloys and Compounds*, **708,** 34-42.

(a4) Cheng Wang, Qi Liu, Douglas G. Ivey and Thomas H. Etsell, 2017, "Bi-Wetting Property of Oil Sands Fine Solids Determined by Film Flotation and Water Vapor Adsorption", *Fuel*, **197**, 326-33.

(a5) Amir Reza Hanifi, Navjot Kaur Sandhu, Thomas H. Etsell, Jing-Li Luo and Partha Sarkar, 2017, "Fabrication and Characterization of a Tubular Ceramic Fuel Cell Based on $BaZr_{0.1}Ce_{0.7}Y_{0.1}Yb_{0.1}O_{3-d}$ Proton Conducting Electrolyte", *J. Power Sources*, **341**, 264-69.

(a6) Bin Hua, **Meng Li**, **Yi-Fei Sun**, **Ya-Qian Zhang**, **Ning Yan**, **Jian Li**, Thomas Etsell, Partha Sarkar and Jing-Li Luo, 2017, Grafting Doped Manganite into Nickel Anode Enables Efficient and Durable Energy Conversions in Biogas Solid Oxide Fuel Cells", *Applied Catalysis B: Environmental*, **200**, 174-81.

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