CURRICULUM VITAE

RODERICK I.L. GUTHRIE, FRSC, FCIM, FCAE, ENG.

Macdonald Professor of Metallurgy
Fellow of the Royal Society of Canada
Fellow of the Canadian Academy of Engineering
Distinguished Member of the AIST
Fellow of the Canadian Institute of Mining and Metallurgy
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Education

Durham Cathedral Choristers School, 1949-1953, (Head Chorister, 1953)
Nottingham High School, 1953-1960
Royal School of Mines, Imperial College, London University, 1960-1967
B.Sc. Hons. (Eng.), A.R.S.M. (Associate, Royal School of Mines), 1963
Ph.D. (Process Metallurgy) 1967, D.I.C. (Diploma of Imperial College), 1967
Full Colours (rowing), Imperial College, London University, 1965.

Academic Positions Held

Assistant Professor, Department of Metallurgical Engineering, McGill University, 1967-1970
Associate Professor, Department of Metallurgical Engineering, McGill University, 1970-1979
Steacie Memorial Research Fellow, NSERC, 1979-1981
Full Professor, Department of Metallurgical Engineering, McGill University, 1979-1986
Macdonald Professor, Dept. of Mining and Materials Eng. McGill University, 1986 -present
Director, McGill Metals Processing Centre, 1990-present

Industrial Positions Held

Resident Consultant, Dofasco Research Centre, DOFASCO, 1970-1990, ALCAN 1979-1986

Introduction

Dr Guthrie is the Director of the McGill Metals Processing Centre, established in 1990. The Centre is concerned with the understanding and description of existing, as well as novel, metallurgical processing operations, for the efficient production of advanced metal-based materials. Using mathematical and physical modelling, the Centre's research activities range from liquid metal processing and refining operations, through solidification, to hot metal deformation, annealing, the development of microstructures, textures, and final product properties. The Centre, spanning five University campuses in Canada, comprises eleven academics specialising in process metallurgy and materials characterisation. Dr Guthrie's core research activities are currently supported technically and financially by an international advisory board of senior members drawn from a group of major metallurgical companies (Currently; NSSMC (Nippon Steel and Sumitomo Corporation), SURAL Quebec, RTIT (Rio Tinto Fer et Titane), TATA Steel (Europe), FORD Motor Company, AMD (Arcelor-Mittal DOFASCO), and FLUENT-ANSYS). In the past, by ALCAN, NOVELIS, ALCOA, DOFASCO, CORUS, QIT, SUMITOMO, NIPPON STEEL, BAOSTEEL, SHOUGANG STEEL, HATCH, HERAEUS-Electronite, FOSECO, Fudutec-Argentina, Manganese Metals Company (S.A.), POSCO (Korea), IVACO, etc.). NSERC, CFI, FQRNT, and DARPA, have provided the remaining sources of funding to support the MMPC's research activities associated with Dr Guthrie's research programs.

Dr Guthrie's personal research interests have centred on the analysis, design, and improvement of metallurgical processes, uniquely emphasizing the role of fluid dynamics in many such operations. Processes that have been researched include the design and operation of (1) BOF steelmaking furnaces (mixing, slag entrainment), (2) ladle steelmaking for mixing and for alloy additions, (3) tundishes for inclusion control and removal, (4) batch annealing furnaces, (5) continuous annealing furnaces and soaking pits, (6) burner firing practices, (7) slab reheat furnaces, (8) flows in aluminum holding furnaces, (9) inclusion sensors for magnesium, copper, aluminum, zinc, steel, (10) thin strip casting, and many others.

Dr Guthrie is the author or co-author of more than 500 publications. He has 11 significant inventions involving about 200 patents, has written three textbooks, five Chapters in handbooks, and been the recipient of many honors and awards, including some twenty three best paper awards.

On the fundamental side, Dr Guthrie has always maintained his interests in the physical properties of liquid metals (e.g., diffusion coefficients, etc.). His book with Dr Iida, the **Physical Properties of Liquid Metals**, published by Oxford University Press in 1988, marked a culmination to that early research, and a new book, The **Thermophysical Properties of Metallic Liquids**. Book 1 Fundamentals, Book 2. Predictive Models, was published last year, again by Oxford University Press. His book, **Engineering in Process Metallurgy**, published in 1989, with revised paper-back editions in 1993, and reprints in 1994 & 2002, marked some 25 years of research in process metallurgy. That book is used globally, and reflects his strong industrial links.
He is also a Co-editor of a three volume set, making up a "**Treatise on Process Metallurgy**", appearing in 2014, by Elsevier. Book 1; **Process Fundamentals**, Book 2; **Process Phenomena**,

Books 3&4; **Industrial Processes**. Series published by Elsevier Press. December 2013, 3450pp. Editor; Seshadri Seetharaman, Co-Editors; Alex McLean, Roderick Guthrie, and Shridar Seetharaman. ISBN: 978-0-08-096986-2. There, he was a lead author for Chapter 8, in Book 2, **Process Phenomena**, entitled "**Metallurgical Process Technology**" pp.497-583.

In terms of industrial contacts, long-term consultancies with Dofasco and Alcan have fostered technology transfer. Such interactions resulted in the important series of *LiMCA* (Liquid Metal Cleanliness Analyser) patents for a method for on-line control of liquid metal quality. This, in turn, led to the production of commercial equipment in 1995 that is currently in global use within the aluminium industry. This breakthrough technology was extended to the steel industry, in 2003, in collaboration with industrial colleagues at Heraeus (USA) and Sumitomo Metals Industries (Japan).

Dr Guthrie has held many shorter term industrial consultancies in Australia, Japan, Brazil and North America. He has presented some twenty short courses on process metallurgy, steelmaking, melt handling of aluminium, and/or fluid mechanics in Australia, Brazil, Canada, United States, Great Britain, Norway and China. Consultation with steel companies has involved extensive "hands-on" summer tours in the respective plants, working on projects in most sectors of an integrated steel plant (i.e., blast furnace, coke ovens, steelmaking, environmental, hot mill and cold mill), as well as equivalent sectors of aluminum plants. Many industrial reports have been produced for these and other companies (e.g., Reynolds Aluminium, Alcan, Liquid Carbonic, Union Carbide Metals Div., Brush-Wellman Copper, QIT, QMP, Atlas, Stelco, Jones & Laughlin, Mount Isa, Comalco, Boeing, Questek, DARPA, etc.etc.).

Dr Guthrie was the Chairman for the 3rd International Steel Congress, held in Charlotte USA, in 2005. He was President of the Metallurgical Society of the Canadian Institute of Mining and Metallurgy (CIM) in 1994. He was responsible for the Quebec City Annual Conference of Metallurgists in 1993, and was responsible for spearheading, with J K Brimacombe, TMS President, joint Student Chapters between MetSoc of CIM and the TMS. He has been a member of the Iron and Steel Section of the CIM for many years, and was its Chairman in 1982-83. He is a founding member, and a former chairman, of the Light Metals Section of the CIM, which was formed in 1988 in recognition of Canada's, and particularly Quebec's, leading role in the global production of aluminium and magnesium.

RESEARCH CONTRIBUTIONS

MOST SIGNIFICANT RESEARCH CONTRIBUTIONS

Inventor of the LiMCA (Liquid Metal Cleanliness Analyzer) with D. Doutre. In 1985, the *in-situ*, real time measurement of liquid metal quality pioneered at McGill, proved to be a major breakthrough for Process Metallurgists. Since then (1985), digital signal processing (DSP) techniques for detecting inclusions were also initiated at McGill. This enabled further information to be obtained regarding inclusion types (harmless micro-bubbles and droplets vs deleterious solids), as well as inclusion numbers, sizes, and size distributions in liquid metals

possible with the original analogue-based detection system. The impact of all these studies have directly contributed to the successful development of commercial equipment by Bomem that is now in use worldwide within the aluminum industry, and in 2004, it came to the steel industry, thanks to Heraeus Electro-Nite. Recent papers with Xiaodong Wang and Mei Li summarize our work on metal quality, and provide a thorough analysis of the important role of magneto-hydrodynamics in orifice "conditioning" and shaping. Patents have been granted for probe designs needed for steel and magnesium melts, the last one issuing in 2003 on the critical role of orifice shape. LiMCA received the Xstrata Innovation Award for 2013, and more recently, the technique is used to measure micro-bubble sizes, in our 4-strand billet caster water model tundish.

Application of Computational Fluid Dynamics(CFD) to Metallurgical Reactor Systems

The applicant pioneered CFD techniques to model metallurgical processing operations, in the mid-70's. Models include steel mixing in ladles, steel and slag flows in tundishes, flows in continuous casting molds, and novel flow systems for liquid metal delivery systems for thin strip casting operations (twin roll and horizontal belts casters). The 1997 Extractive and Process Technology Award from TMS recognized the quality of a three-part CFD paper dealing with inclusion behavior and metal flows in tundish systems, while another received the Canadian Metallurgical Quarterly Best Paper Award. The applicant delivered the 77th Howe Memorial Lecture in 2000AD on the subject of CFD in Metallurgy. He was invited, and organized, a mini-symposium on CFD in pyrometallurgy for the 5th World Congress on Computational Mechanics, held in Vienna, July7-12, 2002. In 2009, he was invited to become an Honorary Member of the ISIJ at which time he delivered an updated version of CFD in steelmaking, entitled, "A review of fluid flows in liquid metal processing and casting operations"

Alloy Additions to Melts

Pioneer in studying the way ferroalloy additions are taken into solution by molten steel. Demonstrated the critical differences between low melting point alloys (which melt within a jacketed shell of frozen steel), and those that dissolve through diffusional processes. Showed the hydrodynamic criteria needed to have these often buoyant additions disperse sub-surface, and analysed addition techniques such as bullet shooting, wire feeding, CAS, addition chutes, etc. together with mixing rates within ladles. Our most recent contribution to this field involves a study of the behaviour of alloy addition compacts to bath of molten Al, and steel. Some plants are using manganese powders highly contaminated with Se. These manganese powders emanate from China, and can be highly toxic in of-gas emissions of selenium dioxide. Our work has demonstrated that most of the Se reports to the off-gas for aluminium melts, or modifies the steels's properties owing to the extremely surface active nature of the Se in Fe.

Strip Casting (Near-net shape casting operations)

Following the invitation of the Canadian Steel Industry (CSIRA) in 1987 to help with the "Projet Bessemer" strip casting program, the applicant has been deeply engaged in all near-net shape casting techniques for the production of sheet material. This lead to the early world-wide filing (with BHP) and granting of patents on enclosed, extended, metal delivery systems for strip casting, and much subsequent research which confirmed the critical requirement for iso-kinetic feeding of metal onto rolls, or belts, and reveals the critical role of interfacial thermal resistances

between strip and substrate. It also reveals the critical role of interfacial thermal resistances between freezing strip and substrate. This fundamental research points the way as to how bulk amorphous alloys may yet be fabricated directly from the melt. Thanks to a major CFI grant, a unique single belt caster for applied research into high speed strip casting of Al, Mg, and steel sheets, was designed and assembled, in collaboration with the Hazelett Strip Casting Company. Since then we have made many good casts of aluminium and steel alloy systems. This fundamental research is supported by a custom-built Horizontal Single Belt Caster, which is now located on Stinson St, Ville St Laurent, under the jurisdiction of MetSim Inc. The process is now slowly gaining acceptance commercially, with Salzgitter Steel's HSBC caster operation in Peine, Germany. Similarly, there are equivalent applications for the casting of light metal (aluminium) sheet alloy products, as per ALCOA's micro-mill sheet aluminum production in San Antonio.

Recent Conference Symposia and Awards

Recent Awards; Honorary Member of AIME 2014, Light Metals/Metaux Legers Best Paper Award of CIM, 2014, AIREY AWARD of MetSoc-CIM 2013 "In recognition of his outstanding achievements in research, and in the development of Process Metallurgy for the light metals and ferrous industries". The XSTRATA INNOVATION AWARD 2013 for the LiMCA System "from its invention by the MMPC at McGill University, to its development and application by RIO TINTO ALCAN and ABB.", The Queens Diamond Jubilee Medal, 2013, The Metal Chemistry Award of CIM 2012, The 2010 Leo Derikx Award of NSERC to the MMPC/Industrial Partners, 2009 Honorary Member of ISIJ, The 2006 **Killam Prize for Engineering**, Queen Elizabeth's Diamond Jubilee Medal, February, 2013. Fellow of the Canadian Academy of Engineering (1999), and of the Royal Society of Canada (1995) for outstanding contributions as an engineer, teacher and inventor. President's Award of Metallurgical Society of CIM (1995), recognizing the introduction of the CIM-TMS Joint Student Chapters Program. Organiser of recent symposia (eg. 2005 International Congress of Steelmaking , Charlotte, May, 2005, Pyrometallurgy mini-symposium at 5th World Congress on Computational Mechanics, Vienna, July 7-12, 2002, 2nd Int'l Congress on the Science and Technology of Steelmaking, Cardiff 2001,. Many keynote presentations;

Academic/Professional Awards and Distinctions

2018 Christophe Pierre Research Award, Faculty of Engineering, McGill University.
Nominated by Chairman, Professor George Demopoulos, Mining and Materials Engineering.

2014 Honorary Member of AIME. This is the senior Society of the TMS, AIST, and SME. Election to this very prestigious group of global members represents the highest form of recognition.

2014 Light Metal/Metaux Leger Best Paper Award of MetSoc, CIM, for the paper; "Continuous casting and product characterization of Al-Mg-Sc-Zr Alloy Strips produced using Horizontal Single Belt Casting (HSBC)".

2013 "The Queen's Diamond Jubilee Medal" received February 17th, 2013, from the Governor General, David Johnston, for "his significant contributions to Canada, to its community, and to its fellow Canadians".

2013 The AIREY AWARD of MetSoc-CIM 2013 "In recognition of his outstanding achievements in research, and in the development of Process Metallurgy for the light metals and ferrous industries".

2013 The XSTRATA INNOVATION AWARD (to the MMPC and Corporate Members) for the LiMCA System "from its invention by the MMPC, McGill University, to its development and application by RIO TINTO ALCAN and ABB."

"Metal Chemistry Award 2012", presented at the Canadian Material Science Conference, London, Ontario, in recognition of his research career, and for his invited lecture "*In – Situ, on-line* Sensors for Liquid Metal Quality"

2010 Leo Derikx Synergy Award of NSERC to R.I.L.Guthrie & M.Isac of the MMPC, and some supporting companies of the Centre; HATCH, Rio Tinto-ALCAN, Heraeus Electro-Nite, NOVELIS.

2009 Honorary Member of the Iron and Steel Institute of Japan; "You were named an Honorary Member of the Iron and Steel Institute of Japan by the unanimous votes of the Board of Directors and the Board of Councillors, in recognition of the distinguished contributions made by you to iron and steel industry"

2006 Killam Prize for Engineering "in recognition of his outstanding achievements and distinguished career contributions"

"The Queen's Golden Jubilee Medal" received 26th March 2003, from the Canadian Governor General, Adrienne Clarkson, for "his significant contributions to Canada, to its community, and to its fellow Canadians".

John E. Elliott Lectureship Award in Chemical Metallurgy, established to acquaint students and engineers with the opportunities in chemical process metallurgy. In appreciation of Dr Guthrie's lectures on*; "Strip casting; the long and winding road"* presented in the year 2003.

2001 Light Metals-Metaux Legers Best Paper Award for paper with J. S. Kim, M Isac, and J. Byun, Title; *"Measurements of interfacial heat transfer resistances and*

characterisation of microstructures for Al-Mg alloys cast on a single belt strip casting simulator"

2001 Benjamin Fairless Award of American Institute of Mining and Metallurgy, "*for his significant contributions to the understanding and knowledge of ferrous metallurgy and for his longstanding commitment with the academic work and formation of new metallurgists"*

2000 Howe Memorial Distinguished Lecturer of Iron and Steel Society of AIME; *For his outstanding accomplishments in the science and practice of ferrous metallurgy, and in appreciation of his lecture entitled "Fluid flow in Metallurgy; friend or foe?"*

2000; J. K. Brimacombe Prize (first recipient) "*for Dr Guthrie's outstanding contributions to Process Metallurgy, as an ambassador, inventor, researcher, and educator".*

1999 CIM Distinguished Lecturer Award

Title "Casting metals in the third millenium"

1999 F.C.A.E. (elected Fellow of the Canadian Academy of Engineers); for outstanding contributions as an engineer.

1998 Best Paper Award of Light Metals Division of MetSoc CIM for paper with M. Isac, R. Tavares, P. Netto, *"The Influence of Solidification and Heat Transfer on Microstructure for Horizontal Strip Casting of Light Metal Alloys".*

1998 Distinguished Member of the Iron and Steel Society, 1998, "for his outstanding contributions of long duration to metallurgical engineering with emphasis on the role of fluid dynamics in metallurgical processing operations."

1997 Extraction and Processing Technology Award of TMS for three best papers with S. Joo, "Inclusion Behavior and Heat-Transfer Phenomena in Steelmaking Tundish Operations: Part I. Aqueous Modelling, and papers with S. Joo and J.W. Han, "Inclusion Behavior and Heat-Transfer Phenomena in Steelmaking Tundish Operations: Part II. Mathematical Model for Liquid Steel in Tundishes and Part III. Applications-Computational Approach to Tundish Design", all published in Metallurgical Transactions B, October, 1993.

F.R.S.C. (Fellow of the Royal Society of Canada), elected 1995; "for outstanding contributions as an engineer, teacher and inventor".

C.I.M. Metallurgical Society President Award 1993 – 1994

Le Prix ASM-Université-Industrie of the Montreal Chapter of ASM International (1993), for his highly successful transfer of *LiMCA* technology from University to Industry.

Best Paper Award of ***Canadian Metallurgical Quarterly*** (1991) with S. Joo for "Heat Flow and Inclusion Behaviour in a Tundish for Slab Casting"

Michael Tenenbaum Award, Mechanical Working and Steel Processing Division of the Iron & Steel Society of AIME, for "The Process Technology of Batch Annealing", **with A.R. Perrin, and B.C. Stonehill of DOFASCO (1988).**

Light Metals Award of T.M.S. (The Metals Society) for "Settling Phenomena in Aluminium Casting Furnaces: A Fundamental and Experimental Investigation", with D. Frayce, **& J.-P. Martin and G. Dubé of ALCAN** (1988).

Extractive Metallurgy Science Award of AIME for; "A Kinetic Analysis of Vacuum Refining of Inductively Stirred Copper Melts", with E. Ozberk (1988).

Fellow of the Canadian Institute of Mining and Metallurgy; "for outstanding contributions to the mining and metallurgical industry, to C.I.M., and to Canada" (1987).

The Alcan Award; "in recognition of applying modern analytical and modelling methods to steelmaking research" (1987).

The Macdonald Professorship Chair; in Mining and Metallurgy, McGill University (1986).

Extractive Metallurgy Science Award of AIME, for a two part paper describing gas driven recirculatory flows in ladles, with Y. Sahai (1984).

The John Chipman Award of AIME, for a fundamental paper on the mechanisms of molten iron desulphurization by magnesium, with G.A. Irons (1983).

Henry Marion Howe Award of ASM, for the best paper to appear in *Metallurgical Transactions*, with G.A. Irons (1982).

E.W.R. Steacie Memorial Research Fellow of Natural Sciences and Engineering Research Council; "for outstanding research in process metallurgy" (1979-80).

Plummer Gold Medal of the Engineering Institute of Canada, for "Magnesium Desulphurization of Iron", with G. Irons (1977).

Charles W. Briggs Award of the Iron & Steel Society of AIME, for the best paper in the Electric Furnace Proceedings (dealing with the kinetics of alloy additions) (1977).

Henry Marion Howe Medal of ASM, for the best paper to appear in *Metallurgical Transactions* ("Hydrodynamic Analysis of Alloy Addition Procedures in Steelmaking"), with H. Henein and R. Clift (1976).

John Chipman Award of the Iron & Steel Society of AIME, for the best paper in Iron and Steelmaking (dealing with thermal/hydrodynamic behaviour of alloy additions to steel baths), with H. Henein and L. Gourtsoyannis (1975).

Marcus A. Grossman Award of AIME, for the best paper in *Metallurgical Transactions* by authors under 38 years of age, (dealing with transient diffusion of a compound gas (CO) into pure iron at 1600°C), with M.Y. Solar (1973).

Best Paper Award of *Canadian Metallurgical Quarterly* for the paper "Melting Rates of Furnace and Ladle Additions in Steelmaking", with L. Gourtsoyannis (1971).

PUBLICATIONS

Books

BOOKS; co-editor of four books in a "Treatise on Process Metallurgy", Editor Prof. Seshadri Seetharaman, Co-Editors; Alex McLean, Roderick Guthrie and Shridar Seetharaman, comprising Book 1; Process Fundamentals, Book 2; Process Phenomena, and Books 3,4; Industrial Processes, 2016.

MMPC researchers contributed Chapter VIII to the second volume "Process Phenomena" as follows; Mihaiela Isac, Kinnor Chattopadhyay, Roderick I.L.Guthrie; "Metallurgical Process Technology" Chapter 8, 164 pages, in Book II "Process Phenomena" of a "Treatise on Process Metallurgy", published December 16th, 2013 by Elsevier Press, as a three volume (4 book) set. ISBN: 978-0-08-096986-2.

Proceedings of the Roderick Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, 2012, Library and Archives Canada, pp 1 – 579, Editor; Mihaiela Isac, Montreal, Canada.

THE PHYSICAL PROPERTIES OF LIQUID METALS *(first edition)*, Takamichi Iida and Roderick I.L. Guthrie. Clarendon Press, Oxford Science Publications, Oxford, England, ISBN 0-19-856331-0, 1988, 288 pages (hardcover).

— A graduate-level book providing the first comprehensive critical survey of those microstructural characteristics of liquid metals which determine their macroscopic properties of viscosity, surface tension, density, heat capacity, thermal conductivity, electric resistivity, diffusion and velocity of sound transmission. The experimental techniques used to obtain these data are also reviewed.

THE PHYSICAL PROPERTIES OF LIQUID METALS *(second edition)*, Takamichi Iida and Roderick I.L. Guthrie. Clarendon Press, Oxford Science Publications, Oxford, England, ISBN 0-19-856394-9, 1993, 288 pages (paperback).

ENGINEERING IN PROCESS METALLURGY *(first edition)*, Roderick I.L. Guthrie. Clarendon Press, Oxford Science Publications, Oxford, England, ISBN 0-19-8562225-0, 1989, 475 pages (hardcover).

— This book is based on the author's development of Process Metallurgy courses at McGill over the first 25 years. It includes many practical examples and exercises, and describes the latest research techniques for numerical modelling of metallurgical reactors, with particular emphasis on liquid flow simulations.

ENGINEERING IN PROCESS METALLURGY, *(second edition)*, Roderick I.L. Guthrie. Clarendon Press, Oxford Science Publications, Oxford, England, ISBN 0-19-856367-1, 1992, 512 pages (paperback). Reprinted in 1993,and in 2002.

Chapters in Books or Handbooks

Roderick Guthrie, Mihaiela Isac; “The Development of Continuous Casting Machines for the Production of Steel in North America”, page 283-288, published in Stranggiesen-Continuous Casting, Aschenfdorff, Verlag, GnbH & Co. KG, Munster, ISBN 978-3-402-13294-4.

Mihaiela Isac, Kinnor Chattopadhyay, Roderick I.L.Guthrie; "Metallurgical Process Technology" Chapter 8, 164 pages, in Book II "Process Phenomena" of a "Treatise on Process Metallurgy",

published December 16th, 2013 by Elsevier Press, as a three volume (4 book) set. ISBN: 978-0-08-096986-2

R.I.L.Guthrie and Mihaiela Isac, "The Design of Continuous Casting Processes for Steel" Chapter 8, in **HANDBOOK of METALLURGICAL PROCESS DESIGN,** ISBN 0-8247-4106-4, Marcel Dekker, New York. 2004, pp251-293

R.I.L. Guthrie, Chapter 7, "Fluid Mechanics in Metallurgical Processes", Advanced Physical Chemistry in Process Metallurgy, Eds W-K Lu, N.Sano, Academic Press, 1997, pp.123-148

G.A. Irons, R.I.L. Guthrie, "Injection Metallurgy", Advances in Materials Science & Engineering, Supplement 3 to Encyclopedia of Materials Science and Engineering, Pergamon Press, Oxford, 1993, pp. 1709-1715.

R.I.L. Guthrie, J.J. Jonas, "Steel Processing Technology", Metals Handbook, Vol. 1, Tenth Edition, pp. 107-125, 1990.

Y. Sahai, R.I.L. Guthrie, "Recent Advances in the Hydrodynamics of Metallurgical Processing", Advances in Transport Processes, Vol. IV, A. Majumdar, Ed., Wiley Eastern, pp. 1-48, 1983.

Publications in Refereed Journals

1. Chang S., Cao X., Zou Z., Isac M., Guthrie R. "Micro-bubble formation under non-wetting conditions in a full-scale water model of a ladle shroud/tundish system", ISIJ International, Volume 58, Issue 1, 2018, Pages 60-67.
2. Zaid Ghouleh, Roderick I.L. Guthrie, Yixin Shao; "Production of carbonate aggregates using steel slag and carbon dioxide for carbon-negative concrete" Journal of CO2 Utilization, 2017, pp 125 – 138.
3. Chang, S., Ge, S., Zou, Z., Isac, M.M., Guthrie, R.I.L., (2016) "Modeling Slag Behaviour when using micro-bubble swarms for the deep cleaning of liquid steel in tundishes", Steel Research Int., Volume 88, Issue 6, June 2017, Paper No 201600328;
4. Roderick Guthrie, Mihaiela Isac, **(invited paper)** "Conventional and Near Net Shape Casting Options for Steel Sheet", Steel World, Ironmaking and Steelmaking, 2016, Vol.43, No 9, pp 650-658
5. Sheng Chang, Xiangkun Cao, Cheng-Hung Hsin, Zongshu Zou, Mihaiela Isac and Roderick I. L. Guthrie: "Removal of inclusions using microbubble swarms in a four strand, full scale, water model tundish"; *ISIJ Int.*, 2016, Vol.56, No 7, pp 1188-1197.
6. Sheng Chang, Xiangkun Cao, Zongshu Zou, Mihaiela Isac and Roderick I. L. Guthrie; "Microbubble Swarms in a Full-Scale Water Model Tundish" *Metall. Mater. Trans. B*, 2016, Vol. **47B**, pp.2732-2743

7. Ge Sa, Sheng Chang, Tong Wang, Luis Calzado, Mihaiela Isac, Janusz Kozinski, and Roderick I.L. Guthrie “Mathematical Modeling and Microstructure Analysis of Low Carbon Steel Strips Produced by Horizontal Single Belt Casting (HSBC)”; Metallurgical and Materials Transactions B, June 2016, Vol 47B, pp 1891-1904
8. Sa Ge, Mert Celikin, Mihaiela Isac, Roderick Guthrie; "Analysis and Evaluation of Novel Al-Mg-Sc-Zr Aerospace Alloy Strip Produced Using the Horizontal Single Belt Casting (HSBC) Process"; Metallurgical and Materials Transactions B, Vol 46B, April 2015, pp1035 - 1043
9. S.Ge, M.Isac, R.I.L.Guthrie; "The Computational Fluid Dynamic (CFD) Modelling of the Horizontal Single Belt Casting (HSBC) and Processing of Al-Mg-Sc-Zr Alloy Strips" Metallurgical and Materials Transactions B, Vol 46B, October 2015, pp. 2264-2276
10. M.Mahdi Aboutalebi, Mihaiela Isac, Roderick I.L.Guthrie; "Magnetic Damping of Liquid Steel Flows in Horizontal Single Belt Casting (HSBC), J. Manufacturing Science and Production, 2015; 15(1): 141-149
11. Roderick Guthrie, Mihaiela Isac, “Horizontal Single Belt Casting of Aluminum and Steel”, Steel Research International, Special Issue: Science and Technology of Steelmaking. Volume 85, Issue (*), pp 1291-1302, August 2014.
12. S. Ge, M. Celikin, M. Isac and R. I. L. Guthrie, "Mathematical Modeling and Microstructure Analysis of Al-Mg-Sc-Zr Alloy Strips Produced by Horizontal Single Belt Casting (HSBC)" *ISIJ Int.*, 54 (2014), pp.*294-303*.
13. Sa GE, Mihaiela ISAC, Roderick Ian Lawrence GUTHRIE; "Progress of Strip Casting Technology for Steel; Technical Developments" ISIJ International, Vol.53 (2013), No.5, pp.729-742.
14. Ken Morales-Higa, R.I.L.Guthrie, M.Isac, and R.D.Morales; "Ladle Shroud as a Flow Control Device for Tundish Operations" Metallurgical and Materials Transactions B, Vol.44, 2013, No 1, pp 112-120
15. Roderick Guthrie, Mihaiela Isac, “In-Situ Sensors for Liquid Metal Quality” Journal of High Temperature Materials and Processes (HTMP), 2012, Vol. 31,No.4/5 pp.633-643.
    A special issue in memory of Professor Dr. Masanori Iwase on “Thermodynamics and Kinetics of Materials Processing”.
16. Kinnor Chattopadhyay, Mihaiela Isac, Roderick Ian Lawrence Guthrie; “Modelling of Non-isothermal Melt Flows in a Four Strand Delta Shaped Billet Caster Tundish Validated by Water Model Experiments; ISIJ International,Vol. 52 (2012) No. 11, pp 2026 – 2035.
17. Patrick Lemieux, Roderick Guthrie & Mihaiela Isac; “Optimizing Soft Magnetic Composites for Power Frequency Applications and Power-Trains”, Journal of Metals, JOM, March 2012, Volume 64, Issue 3, pp 374-387.
18. Ge Sa, Mihaiela Isac and Roderick Guthrie; “Progress of Strip Casting Technology for Steel; Historical Developments”, Iron and Steel Institute of Japan, Vol. 52 (2012), No. 12, pp. 2109–2122.
19. Kinnor Chattopadhyay, Mihaiela Isac and Roderick Guthrie:" Effect of Flow Modifiers on Liquid Metal Cleanliness in a Four Strand Delta Shaped Billet Caster Tundish" Ironmaking and Steelmaking, 2012,Volume 39, Number 6, pp.454-462

20. Kinnor Chattopadhyay, Mihaiela Isac and Roderick I.L.Guthrie: "Effect of submergence depth of the ladle shroud on liquid steel quality output from a delta shaped four strand tundish", Ironmaking & Steelmaking, Volume 38, Number 5, July 2011 , pp. 398-400
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Note: In the metallurgical community, it is not common practice to submit refereed conference papers to journals. i.e. Conference Proceedings are treated as being archival in nature. A careful checking of the titles of the journal papers and conference proceedings will reveal very little overlap, as for certain other scientific and engineering communities in which conference papers are then submitted to archival journals (e.g. chemical engineering).

1. Roderick Guthrie, Mihaiela Isac; "Forming Micro-bubbles in Liquid Steel", Proceedings of the 3rd International Conference on Science & Technology of Ironmaking and Steelmaking (STIS-2017), IIT Kanpur, India, 11-13 December, 2017, Paper code 13FNL11KN33.
2. M. Mahdi Aboutalebi, M. Isac, R.I.L. Guthrie; "The effect of the position of a submerged entry nozzle's (SEN) exit ports on fluid flows and meniscus stability, for square billet moulds", ECCC, 9th ECCC European Continuous Casting Conference 2017, Vienna, Tuesday, June 27th.
3. Roderick Guthrie, Mihaiela Isac, Xinyu Roger Ren, "The Fundamentals of Forming Micro-Bubbling in Liquid Metal Systems", Proceedings of The Science of Melt Refining, Thorvald Abel Engh & Christian Siemensen Honorary Symposium, Symposium, TMS 2017, San Diego, California.
4. Xiangkun Cao, Sheng Chang, Cheng-Hung Hsin, Luis E. Calzado, Mihaiela Isac and Roderick I. L. Guthrie. "Aqueous Particle Sensor (APS) for microbubble detection in a four strand, full scale, water model tundish" COM/IMPC 2016 Proceedings, Paper 963, Québec City, Canada, September 11–15, 2016.
5. M. Mahdi Aboutalebi, Mihaiela Isac, and Roderick. I.L. Guthrie, "The Effects of Nozzle Geometry on the Fluid Flows in the Round and Square Billet Molds", COM 2016 Proceedings, Quebec City, September 11 - 15, 2016.
6. Roderick I. L. Guthrie, Mihaiela Isac "Computational Fluid Dynamic Modelling of Horizontal Single Belt Casting (HSBC) of Steel Strips; Numerical and Modelling Issues, "Numerical Computations: Theory and Algorithms" -NUMTA 2016 Proceedings, Pizzo Calabria, June 19- June 25, 2016.
7. Roderick Guthrie (invited keynote); "Generation of micro-bubbles to improve bottom pour ingot quality", Ingot Metallurgy Forum, IMF Fall Technical Meeting, October 25-26th, 2016, State College, Pennsylvania.
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10. K. Chattopadhyay, S.Chatterjee, M.Isac, R.I.L.Guthrie; "Effect of non-isothermal melt flows on liquid metal quality in a tundish"; METEC-ESTAD2015, June 17, Duesseldorf, Germany, p. 24, Steelmaking.
11. Roderick Guthrie, Mihaiela Isac, **Invited**; "The Probability of Near Net Shape Casting of Steel Sheet; Twin Roll Casting and/or Horizontal Single Belt Casting?" CTSSC-EMI Symposium, Tokyo, September 3-5, 2015, pp 300-311.
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13. Roderick Guthrie, Mihaiela Isac, **(Invited)** `Horizontal Single Belt Casting of AA6111 Auto-Alloys, including Predictions and Measurements of Interfacial Heat Transfer and Solidification during the first Critical Moments of Melt-Substrate Contact, Conference Proceedings, Ravi Ravindran Honorary Symposium, MS&T 2014, Pittsburgh, USA, 16 August 2014, pp.105-117.
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18. Mert Celiken, Donghui Li, Luis Calzado, Mihaiela Isac; "Horizontal single belt strip casting (HSBC) of Al-Mg-Sc-Zr alloys", TMS Spring Conference, San Antonio, 2013. pp 201-206
19. Ken Morales-Higa, R.I.L.Guthrie, M.Isac; "A fluid flow and steel intermixing study of a round billet mould" May 6-9, 2013, AIST annual steelmaking conference, Pittsburgh, pp.1373-1384
20. Ken Morales-Higa, R.I.L.Guthrie, M.Isac; "The effects of fluid flow on flux entrainment in a square billet mould" May 6-9, 2013, AIST steelmaking conference, Pittsburgh, pp.1461-1472
21. A.Kaiser Hamid, Mihaiela Isac, R.I.L.Guthrie; "Effect of an optimised impact pad on molten steel quality in a 4-strand delta-shaped tundish" May 6-9, 2013, AIST steelmaking conference, Pittsburgh, pp.2143-2154

22. Roderick Guthrie, Mihaiela Isac; (invited) "The prospects for NNSC processes being adopted by the steel industry", 68th ABM (Association of Metallurgical, Materials, and Mining Association) International Congress, 30th July - August 2nd, 2013, Expominas, Minas Gerais, Brazil. pp. 31-40
23. Roderick Guthrie, Mihaiela Isac; "Computational Fluid Dynamics and Experimental Results for the Horizontal Single Belt Casting (HSBC) of aluminum alloy strips" PRICM 8 (Pacific Rim Int'l Conference of Metallurgists), Waikoloa, Hawaii, Aug. 4-9, 2013, pp 1162-1170
24. R.I.L.Guthrie, M.Isac, X.R.Ren; **(invited)** "The Fundamentals of gas bubbling into liquid metals" Ralph Lloyd Harris Memorial Symposium, MS&T COM 2013, October 27-31, Montreal, Quebec, pp. 343-357
25. A.Hamid, M.Isac, R.Guthrie; "Analysis of Residence Time Distribution (RTD) of fluid in a four strand delta-shaped tundish operating under isothermal and non-isothermal conditions" MS&T COM 2013, October 27-31, Montreal, Quebec, pp. 439-447
26. Ken Morales-Higa, R.I.L.Guthrie, M.Isac, R.D.Morales, C.Labrecque, F.Lapointe; "Mathematical modelling for multiport nozzle optimisation in a round billet mold", MS&T COM 2013, October 27-31, Montreal, Quebec, pp. 448-460
27. S. Ge, M. Celikin, M. Isac and R. I. L. Guthrie, "Mathematical Modeling and Validation of an Al-Mg-Sc-Zr Alloy Strip, Produced using Horizontal Single Belt Casting (HSBC), Proc. of Mat. Sci. & Tech. (MS&T) 2013, Montreal, Canada, (2013), pp1113 - 1123.
28. M. Celikin, S. Ge, D.Li, L.Calzado, M. Isac and R. I. L. Guthrie, "Continuous Casting and Product Characterization of Al-Mg-Sc-Zr Alloy Strips Produced via Horizontal Single Belt Casting (HSBC)", Proc. of Mat. Sci. & Tech. (MS&T) 2013, (Edited Barry Sadler), Montreal, Canada, (2013), pp.1243-1251
29. Roderick Guthrie, Mihaiela Isac, "Near Net Shape Casting of Steels; the way forward?" **Invited paper** at the International Conference on Science and Technology of Ironmaking and Steelmaking (STIS - 2013), Jamshedpur, India, Dec 16-18, 2013, pp 1-15
30. Donghui Li, Mihaiela Isac, Roderick Guthrie. "Improving Strip Surface Quality of AA6111 alloy using Different Casting Atmospheres for the Horizontal Single Belt Strip Casting (HSBC) Process" Light Metals 2012, Edited by Carlos E. Suarez, Proceedings of the 2012 TMS Annual Meeting & Exhibition, San Diego, USA, pp. 1101-1105
31. Roderick Guthrie **(Keynote Address)**: Improving Flows in Steel Making Tundishes, Symposium on Science and Technology of Metals, Materials for Modern Society, in honour of Professor dr. Robertus Boom, The transition to Emeritus Professor, Delft University, March 30, 2012.
32. Roderick Guthrie. **Keynote Lecture in receipt of the Metal Chemistry Award 2012** at the 24th Canadian Materials Science Conference, London, Ontario, Canada, June 7th, 2012. Presentation for **Chemical Metallurgy Award Lecture entitled** "In – Situ Sensors for Liquid Metal Quality"
33. Roderick Guthrie, Mihaiela Isac; "In-Situ Sensors for the direct detection of inclusions in liquid steel", Proceedings of the 8th Conference on Clean Steel, Budapest, Hungary, 14 – 16 May, 2012, MVAE Association of the Hungarian Steel Industry, pp 1-12

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35. Ge Sa, Kinnor Chattopadhyay, Mihaiela Isac, Roderick I. L. Guthrie, " Mathematical Modelling of Transport Phenomena in Horizontal Single Belt Casting (HSBC)" Proceedings of the 5th International Congress on the Science and Technology of Steelmaking 2012, Dresden, Oct. 1-3**,** ICS 2012, pp 1-12.
36. Roderick Guthrie, Mihaiela Isac **(Keynote Address)**: "Horizontal Single Belt Casting of Aluminum and Steel" Proceedings of the 5th International Congress on the Science and Technology of Steelmaking, ICS 2012, Dresden, Oct 1-3, pp 1-11
37. "A Review of some Applications of CFD Modelling to Enhance Liquid Steel Quality in Ladles and Tundishes" Roderick I.L.Guthrie, Mihaiela Isac, and Kinnor Chattopadhyay, METEC, STEELSIM, 2011, June 27- July 1, Dusseldorf, Germany
38. Kinnor Chattopadhyay, Mihaiela Isac, Roderick Guthrie, "The concept of microbubbles within a tundish; physical and mathematical modeling", METEC, STEELSIM, 2011, June 27-July 1, Session 16, pp 1-9, Dusseldorf, Germany.
39. R.I.L.Guthrie, M.Isac,and Donghui Li; "The Direct Observation and Modeling of Metal Flows in the Primary Meniscus Regions of Near Net Shape Casting Processes" Invited Keynote, Int.14, CAMP-ISIJ , Vol.24 (2011), 510-513
40. Roderick I.L.Guthrie, Mihaiela Isac, and Kinnor Chattopadhyay, "A Review of some Applications of CFD Modelling to Enhance Liquid Steel Quality in Ladles and Tundishes" METEC, STEELSIM, 2011, June 27- July 1, Session 4, pp 1-10, Dusseldorf, Germany.
41. Patrick Lemieux, Mihaiela Isac, Roderick Guthrie; "On the path to optimising soft magnetic composites", Proceedings of the IEEE Conference, SMM20, Soft Magnetic Composites, Kos Island, September 14 -18, 2011.
42. Roderick I.L.Guthrie (Invited Keynote),Mihaiela Isac, Kinnor Chattopadhyay "Some examples of the application of computational fluid dynamics to enhance liquid steel quality in tundishes" Proceedings of the Richard J. Fruehan Symposium, June1-2, 2011, Carnegie Mellon University, pp 153-162
43. Mihaiela Isac (Keynote Speaker), Roderick Guthrie; "The development of Process Metallurgical Research at McGill University, and its Impact on Industry" Proc.Roderick Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, Library and Archives Canada, pp 3-16.
44. Roderick I.L.Guthrie,(Invited Keynote), Mihaiela Isac; "In-situ sensors for liquid metal quality" Sensors, Sampling, and Simulation for Process Control, Editors B.G.Thomas, J.A.Yurko, and L.Zhang. TMS (The Minerals, Metals & Materials Society), 2011, pp.3-14.
45. Mihaiela Isac, Abhishek Chakraborty, Luis Calzado, Roderick Guthrie; "Development of an aqueous particle sensor (APS II) system as a research tool for studying the behaviour of inclusions in water models of tundish operations"Sensors, Sampling, and Simulation for Process Control, Editors B.G.Thomas, J.A.Yurko, and L.Zhang. TMS (The Minerals, Metals & Materials Society), 2011, pp.27-34.
46. Donghui Li, Jaspreet Gill, Mihaiela Isac, Roderick Guthrie; "Studies of Fluid Flow and Meniscus Behaviour during Horizontal Single Belt Casting (HSBC) of thin metallic strips",

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47. Donghui Li, Mihaiela Isac, Roderick Guthrie; "Studies of casting Ca-based amorphous strips via horizontal single belt strip casting process"Proceedings of the Roderick Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, pp.445-451.
48. Donghui Li, Mihaiela Isac, Roderick Guthrie; "The Direct Observation and Modelling of Metal Flows in the Meniscus Regions of Horizontal Single Belt Strip Casting Process"Proceedings of the Roderick Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, pp.452-459.
49. Luis Calzado, Mihaiela Isac, Roderick Guthrie; 'Modelling the Shrouding of a Supersonic Oxy-Fuel Burner System" Proceedings of the Roderick Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, pp.460-464.
50. Luis Calzado, Mihaiela Isac, Roderick Guthrie; "Characterization of Co-Firing Combustion in a Pilot -Scale Multi-Mode Combustor as a Single Burner Furnace" , 2011, Proceedings of the Guthrie Honorary Symposium on Process Metallurgy, MMPC, ISBN #978-0-986968-0-6, pp.465--468.
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52. Patrick Lemieux, Kinnor Chattopadhyay, M. Isac, R. I.L. Guthrie, M. Hasan, "Computer Modeling of the Die-Wall Lubrication Process Using the 'Confining Block' Technique", POWDER MET 2010, June 27-30, Fort Lauderdale, Florida, USA, pp 11-18
53. Patrick Lemieux, Fabrice Bernier, Yannig Thomas, Mihaiela Isac and Roderick I.L. Guthrie, "Sintered Lamellar Soft Magnetic Composite fabricated with Fe, FeNi and Fe3%Si", Proceedings of the POWDER MET 2010, June 27-30, Fort Lauderdale, Florida, USA
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55. Roderick I. L. Guthrie, Mihaiela Isac, Donghui Li, "*Ab-initio* Predictions of Interfacial Heat Flows during the High Speed Casting of Liquid Metals in Near Net Shape Casting Operations", Proceedings of the Seetharaman Symposium, Sigtuna, June 15-17, 2010, Sweden, appearing in Steel Research International, October, Vol.81, 2010. pp 891-898.
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Inventions and Patents

1. Mei Li, Roderick.I.L.Guthrie; "Molten Metal Inclusion Sensor Probes" U.S.Patent 6,566,853 B2, issued May20th. 2003, plus counterpart patents for Japan, Korea, and Canada.
2. R.I.L. Guthrie, H. Nakajima, "Continuous-Use Molten Metal Inclusion Sensor", Canadian Patent 2,053,298, March 13th, 2001
3. R.I. L. Guthrie; "Molten Metal Inclusion Sensor Probes". U.S. Patent 5,789,910. Aug 4th, 1998
4. R. Sankaranarayanan, R.I.L. Guthrie, "Flow Control Device for the Suppression of Vortices", Canadian Patent Appln. No. 2,084,845-6, December 8, 1992; U.S. Patent 5382003, January 17, 1995.
5. H. Nakajima, R.I.L. Guthrie, "A Single-Use Probe for Detecting Inclusions in Liquid Steel", U.S. Patent 5,198,749, March 30, 1993. Filings made for 20 other countries, courtesy of Electro-Nite, USA and Sumitomo Metals Industries, Japan.
6. H. Nakajima, R.I.L. Guthrie, "Continuous-Use Molten Metal Inclusion Sensor", Japanese Patent Appln. No. 1/108872 pending; U.S. Patent 5,241,262, August 31, 1993; filings in other countries, courtesy of Electro-Nite, USA and Sumitomo Metals Industries, Japan.
7. J. Herbertson, R.I.L. Guthrie, "Continuous Casting of Thin Metal Strip", Canadian Patent 536533, March 3, 1992 and U.S. Patent 4,928,748, May 29, 1990. Counterpart patents, courtesy of BHP (Australia).
8. D. Doutre, R.I.L. Guthrie, "Apparatus for the Detection and Measurement of Particulates in Liquid Metals", U.S. Patent 4-600-880, July 15, 1986.
9. D. Doutre, R.I.L. Guthrie, "A Method and Apparatus for the Detection and Measurement of Particulates in Liquid Metals", U.S. Patent 4,555,662, November 26, 1985. With counterpart patents, courtesy of Alcan, issued in Australia (564,184), Brazil, Canada (1203996), Austria, Belgium, Germany, France, Switzerland, Great Britain, Italy, Luxembourg, Netherlands, Sweden, Norway, South Africa (84/1303), Mexico, India, S. Korea, Japan, Spain (530 246).

10. R.I.L. Guthrie, A.R. Perrin, B.C. Stonehill, B.F. Johnston, "The Loading System for an Annealing Furnace Charge and Components Thereof", U.S. Patent 4-412-815, November 1983.
11. R.I.L. Guthrie, F. Mucciardi, "A Method of Melt Dispersing a Floatable Solid Additive in Molten Metal and a Melt Dispersible, Floatable, Solid Additive Therefore", U.S. Patent 4-277-282, Canadian Patent 1119814, Japanese Patent Appln. No. 44514/80.

N.B. Of the **eleven inventions**, the more important ones, including four Inclusion sensor inventions, the extended metal delivery system for strip casting and the vortex busters, were patented on a world-wide basis, with patents issuing in 28-30 countries. The total number of patents issued therefore approximates 200 patents.

Invention #4 refers to a practical way whereby the adventitious carry-over of slag droplets resulting from **vortexing** can be eliminated. This work is currently being tested in steel plants (tundishes) in collaboration with Foseco International.

Inventions #8 and #9 describe a method and apparatus to monitor, for the first time ever**, liquid metal quality** (number and density and size distribution of inclusions) on-line. This patent has been of major significance and implication for the in-situ detection of inclusions in liquid metals, for which worldwide coverage was sought and granted.

Inventions #2 and #5 describe extensions of the basic in-situ inclusion sensor concept to the rather difficult materials problem of detecting 10-200 mm particles in **liquid steels** at temperatures up to 1650°C.

Invention #3 resolves materials problems for detecting inclusions in **molten magnesium** and copper by using concentric steel tubes that are separated by an insulating air gap.

Invention 1 demonstrates the critical importance of optimising the shape and dimensions of the ESZ orifice, in order that the **magneto-hydrodynamic force-field effects** associated with the extremely high current densities applied to generate detectable electrical signals using the resistive pulse technique , be used to maximum advantage in the detection and discrimination of inclusions.

Invention #7 concerns a novel approach to the problem of delivering liquid metal for the **high-speed thin-strip casting** of liquid metals, and particularly molten steel. Its purpose is to produce sheet, 2-20 mm thick, at productivities matching today's large slab caster in a friction-free fashion, within a controlled, pressurized, laminar flowing liquid metal environment. Similar, but independent approaches are being pursued by two other groups: the first being Professor Klaus Schwerdtfeger in collaboration with Mannesmann Demag and the second, a consortium of steel companies supporting Mefos, Lulea, Sweden.

Invention #10 describes a new design for retro-fitting **batch annealing** units of the sand-seal variety (of which Dofasco has some 340), and achieving a 10-15% productivity gain at no extra energy input. These flow modifications were carried out, and some furnaces were also adapted to

the recirculation of hydrogen gas, vs HNX gas mixtures, again to increase heat transfer rates between the vertically stacked coils of steel and the furnace covering hood..

Invention #11 teaches a method whereby the heating, melting, and dissolution of **low-melting-point alloy additions** (e.g., Al, Fe-Mn, Fe-Si, etc.) with respect to baths of liquid steel, can be made to disperse more rapidly than nature would normally allow, by preventing steel shell formation in localized parts of a submerged body (e.g., Al bullet).

Conference Symposia

As an active member of the various metallurgical societies, Dr Guthrie has helped with many conference symposia on steelmaking and light metals. These include co-editing and/or organizing the following International and CIM symposia proceedings:

International Steel Congress, 2005, Charlotte, North Carolina, May 8-12th, 2005 (Congress Chairman), with AIST staff and co-chairs Dr Mihaiela Isac, MMPC, and Prof Alan Cramb, Carnegie Mellon University.

Pyrometallurgy mini-symposium (organizer) at 5th World Congress on Computational Mechanics, Vienna, July 7-12, 2002,

International Steel Congress, 2001, Cardiff, Wales (International Advisory Board member), Institute of Metals.

International Symposium: Light Metals 1997 Métaux Légers, 36th Annual Conference of Metallurgists, CIM, Sudbury, 1997 (Symposium Organizer/Editor).

International Symposium on Developments in Ladle Steelmaking and Continuous Casting, Annual Conference of Metallurgists, CIM, Hamilton, 1990.

International Symposium on Ladle Steelmaking and Furnaces, Annual Conference of Metallurgists, CIM, Montreal, 1988.

International Symposium on the Production of Liquid Aluminum, Annual Conference of Metallurgists, CIM, Toronto, 1986 (First ever proceedings of the Light Metals Section).

International Symposium on the Physical Chemistry of Iron and Steel Making, Annual Conference of Metallurgists, CIM, Toronto, 1982. This marked the first of MetSoc's CIM many Symposium Proceedings, and established the model of holding symposia at which the proceedings were available at the Conference itself. This has since been adopted by TMS and recently ISS.

Visiting Professor for Short Courses/Lecture Courses in Process Metallurgy, Steelmaking and Aluminum Cast House Practices:

1979 Catholic University of Rio de Janeiro (P.U.C.), Brazil, 1979
1980 University of Toronto, 1980
1981 Technical University of Nova Scotia, 1981

1983 Carnegie-Mellon University, Center for Iron and Steelmaking Research, USA, 1983
1983 University of Surrey, Department of Chemical Engineering, 1983-1984
1983 University of Chongqing, China, 1983
1985 University of Melbourne, Australia, 1985, 1989 and 1991
1993 University of Trondheim, NTH, Norway, 1993
1994 Central University of Venezuela (School of Metallurgy & Materials Science, Venezuela)
1995 Institute for Advanced Materials Processing, Tohoku University, Sendai, Japan, 1995
1996 Royal Institute of Technology, Stockholm, Sweden, 1996
2001 Instituto Argentino de Siderurgia, Buenos Aires, October 2001 (500 pages course notes- the roles of fluid mechanics in iron and steel making operations)
2003 University of Greenwich, School of Computing and Mathematical Science, England, 2003.

Professional Activities

Professional Honors:

- Honorary Member of the AIME
- Honorary Member of Iron and Steel Institute of Japan.
- Distinguished Member of the Iron and Steel Society of AIME (now AIST of AIME)
- Fellow of the Canadian Academy of Engineering (FCAE)
- Fellow of Royal Society of Canada (FRSC), Director ASE division (1998-2000)
- Fellow Canadian Institute of Mining and Metallurgy (President MetSoc 1992)
- Editorial Board, *Transactions of the AIST (Assocn for Iron &Steel Technology)*
- Editorial Board, Aluminium Transactions
- Editorial Board, Institute of Metals
- Canadian WHO'S WHO, 1990 - present

McGill Appointments:

- Director, McGill Metals Processing Centre, 1990 - present
- President, McGill Faculty Club, 1997-1999
- Board of Directors, Brace Research Institute, 1990-2000

Membership in Professional Societies:

Canadian Academy of Engineering
Canadian Institute of Mining and Metallurgy
Association for Iron and Steel Technology
Royal Society of Canada
The Metals Society (TMS)
Iron and Steel Institute of Japan
L'Ordre des Ingénieurs de Québec

Professional and Consulting Experience (Process Metallurgy)

Atlas (Welland, Tracey), Q.I.T., Q.M.P., Stelco, Dofasco, A.E.C.L.(Atomic Energy of Canada), Alcan, Reynolds Aluminum, Intalco, Comalco, B.H.P., Norsk Hydro, Elkem, Acme Steel, Foseco, Vesuvius, Dow, Metglas, L.T.V., Union Carbide, Wheeling-Pitt, Sumitomo, Nippon Steel, Sollac, Pechiney, NUCOR, Bethlehem Steel, Boeing, Kamyr, etc. etc.

Industrial work experience as on-site consultant

Stanton Iron Castings, Foundry Work, 1961 (as student)

National Coal Board, Hounslow, U.K.,1962, "High Manganese Steels for Pit Props" (as student).

Atlas Steels, Welland, Summer 1968, "Solidification of Tool Steels and the role of macro-carbides"

AECL, Atomic Energy of Canada, Chalk River, Summer 1969, "The Thermal Erosion of Steel Pipes by Molten Lead - Bismuth Alloys".

Dofasco, Hamilton, 1970, "Oil Injection into Blast Furnaces. "Development of a Spray Nozzle for No.3 Blast Furnace"

Dofasco, Hamilton, 1972, "Dissolution of Hot Mill Crop Ends into Hot Metal in Transfer Ladles for IRSID Continuous Steel making Reactor".

Dofasco, Hamilton, 1973, "BOF Slag Recycle to the Blast Furnace - Role of High Manganese Levels".

Dofasco, Hamilton, 1974-1983, Mathematical and physical models for improving various processes;

1) Particle settling in No. 3 Blast Furnace Clarifier System,

2) Hot Strip Mill: Minimum run-down temperatures for transfer bar (hot slab),

3) Hot Mill Run-Out Cooling System - Development of laminar flow water curtain cooling system,

4) Model of Silicon Steel Annealing Furnace,

5) Batch Annealing - Mathematical and physical models for understanding, monitoring and improving the performance of batch annealing system,

6) Model of "Spent Liquor" re-cycle system in coke oven battery main,

7) Model of Galvannealing furnace heating/cooling system

I took a sabbatical UK 1983-1984 at University of Surrey, Chemical Engineering Department.

Dofasco, Hamilton, 1984 - 1990, "Mathematical and physical models for" ;

1)Tank Degasser System - Dual Porous Plug, Reactor Kinetics

2) #2 Melt Shop70 Tonne Tundish - Modelling of Flow Control Devices

3) Hot Mill No. 2 Slab Caster System - Solidification and Heat Transfer Model (1D and2D)

4) Italiampienti Slab Reheating Furnace - Characterisation and Modelling (Directed large team of McGill researchers doing on-line heat and mass balance studies, based on a $1.1M NSERC Co-operative Research and Development Grant)

PERSONNEL TRAINED

Undergraduate core courses taught.

Advanced Process Metallurgy, (developed), 1967-1993
Extractive Metallurgy, MIME 350, 1970-1980,
Heat, mass, and fluid flows in Metallurgy, (developed), 1990-2003, MIME 356
(Responsible for the overhaul of undergraduate curriculum with HH Yates when McGill adopted the credit course, vs term, system, in ~ 1980)

Introduction to Extractive Metallurgy, MIME 250, 2008-present
Steel making and Steel Processing, (developed), MIME 456, 1980-present
Process and Materials Design, MIME 452, 2003-present

Current Graduate Students, Post-Doctoral Fellows, Research Associates (up until ~2010)

Master's and Doctoral Students
Zaid Ghouleh; M.Eng. The treatment of fly-ash to form stabilised glassy-crytalline products.
Kinnor Chattopadhyay, M.Eng.; "The role of gas shrouded nozzles in Tundish metal flows and associated melt cleanliness.
Patrick Lemieux, Ph.D.; "The production of soft lamellar composites for electric motor armatures via strip cast steel foil sheets using the single wheel, melt extraction, approach"
Shamik Ray, Ph.D.; "Isothermal, and non-isothermal steel flows, and steel quality, in a 4 strand, delta shaped tundish".
Afshar, Reza , Ph.D. Thesis, "Electromagnetic filtration of magnesium alloy systems"

Post-Doctoral Students
Li ,Donghui, 2003, Mathematical and physical modelling of single belt casting (presently PDF).
Wang, Xiaodong, 2009, Mathematical and physical modelling of electromagnetically affected flows in metallurgical processing operations.
Calzado, Luis; 2007, Environmental projects and furnace operations
Isac, Mihaiela (Professor, Bucharest) and Research Manager MMPC. The physical metallurgy of the various strip casting metal alloy projects under investigation.

Graduates Supervised

Amr Sobhy, Ph.D. 2007, "Novel approaches towards conversion of organics in supercritical water", now Res.Assoc. Univ. de Montreal.
Humeniuc, Dan. M.Eng.2006 "The design and operation of a pilot scale, single belt caster" (now engineer, with ALGOMA Steel
Kim, Jinsoo, PhD., 2006, "The role of the interface, in the high speed, thin strip casting, of aluminium, and magnesium alloys".(now with Samsung, Korea)
LeBoeuf, Sebastien, Master Eng Thesis, 2004, "The interrelationship between heat fluxes and wetting angles".(now with ALCAN, Arvida)
Moon, Kihyeon , PhD., 2003, "Delivery systems for Horizontal Belt Casting of Steel and Non Ferrous Alloys", " (Senior Researcher, POSCO, Korea).

Saeed Rastegari, PhD., 2002, "The Effect of Platinum and Chromium on Aluminide Coatings of IN-738LC" (now Prof., Univ.Tehran)

Kim, Hyoungbae, PhD, 2003, "Collector-Shroud Nozzle Assembly for Continuous Casting of Steel" (now with QIT Rio Tinto, Canada)

Li, Mei, Ph.D., 1999, "Mathematical and Physical Modelling of Magneto-hydrodynamics (MHD) in LiMCA Technology".(now with Ford Motor Company, Research Department, USA).

Netto, Pedro G.Q., Ph.D. 1998, "Horizontal Belt Thin Strip Casting of Steel". (now Vice President, Companhia Vale de Rio Doce, Brazil)

Tavares, Roberto P., Ph.D. Thesis, 1998. "Vertical Twin-Roll Caster: Metal-Mould Heat Transfer, Solidification and Product Characterization". *Current position:* Associate Professor, Universidade Federal de Minas Gerais, Brazil.

Lin, Zuohua Joseph, Ph.D. Thesis, 1997. "The Modelling of Emulsification, Slag Foaming and Alloy Addition Behaviour in Intensively Stirred Metallurgical Reactors". *Current position:* Danieli, Beijing, China.

Abuluwefa, Hussein, Ph.D. Thesis, 1996. "Oxidation Kinetics of Steel Substrates". *Current position:* Professor, Libya

Shafyei-Najafabadi, Ali, Ph.D. Thesis, 1996. "Dissolution of Powders in Molten Aluminum". *Current position:* Professor, Isfahan University of Technology, Isfahan, Iran.

Jefferies, Carol, Ph.D. Thesis, 1995, "Modelling a Novel, Thin Strip, Continuous Steel Caster Delivery System". *Current position:* Math Professor, Mont Royal Community College, Calgary, Alberta.

Tian, Chenguo, Ph.D. Thesis, 1995. "Filtration of Liquid Aluminium with Reticulated Ceramic Filters". *Current position:* Research Scientist, CSIRO, Australia.

Draganovici, Tudor, M.Eng. Thesis, 1995. "A User Friendly Software Interface for the Liquid Metal Cleanliness Analyzer (LIMCA)". *Current position*: Engineer, CAE Electronics, Montreal, Quebec.

Shi, Xiadong, M.Eng. Thesis, 1994, "Upgrading Liquid Metal Cleanliness Analyzer (LIMCA) with Digital Signal Processing (DSP) Technology". *Current position*: Engineer, Newbridge, Ottawa, Ontario.

Sankaranarayanan, Ramani, Ph.D. Thesis, 1994, "Modeling of Slag Entraining Funnel Formation ('Vortex') During Liquid Metal Transfer Operations". *Current position*: Engineer - Process Metallurgy, Hatch Associates, Mississauga, Ontario.

Aboutalebi, M. Reza, Ph.D. Thesis, 1994, "Physical and Mathematical Modelling of Continuous Casting Systems". *Current position:* Professor, Iran University of Science and Technology, Tehran Iran.

Lee, Hyoung Chul, Ph.D. Thesis, 1994, "On the Development of a Batch Type Inclusion Sensor in Liquid Steel". *Current position*: advisor to the President, Yangshin Steel, Korea

Murakami, Hideki, Ph.D. Thesis, 1993, "Modelling of Turbulent Flow, Heat Transfer and Solidification in a Twin-Roll Caster". *Current position:* Senior Researcher, Nippon Steel Technical Development Bureau, Japan.

Yamanoglu, Guler, M.Eng. Thesis, 1993, "Characterization of Submerged Powder Injection into Water Using an In-line Particle Detection System".

Kulunk, Bahadir, Ph.D. Thesis, 1992, "Kinetics of Removal of Calcium and Sodium by Chlorination from Aluminum and Aluminum-1wt% Magnesium Alloys". *Current position:* Senior Research Investigator, STAS, Chicoutimi.

Mahfoud, Musbah, M.Eng. Thesis, 1992, "The Wettability of Ceramic-coated Steel Substrates by Liquid Metals". *Current position*: Engineer, Timminco Metals, Ontario.

Abuluwefa, Husein, M.Eng. Thesis, 1992, "Scale Formation in a Walking-Beam Steel Reheat Furnace".

Verhelst, Dominic, M.Eng. Thesis, 1991, "Physical Modelling of Gas Stirred Metallurgical Reactors Containing Two Liquids". *Current position:* Smelter technical foreman, Hudson Bay Mining & Smelting Co., Ltd., Flin Flon, Manitoba.

Joo, Sanghoon, Ph.D. Thesis, 1990, "Modelling Metallurgical Phenomena in Ladle and Tundish Steel Processing Operations". *Current position:* Principal researcher, Research Institute of Industrial Science & Technology (RIST), Pohang, Korea.

Frayce, Denis, Ph.D. Thesis, 1990, "Hydrodynamics, Heat and Mass Transfer Phenomena in Reverberatory Furnaces: Mathematical Modelling and Experimentation". *Current position:* Research Associate, Industrial Materials Institute, Boucherville, Quebec.

Tian, Chenguo, M.Eng. Thesis, 1990, "On the Removal of Non-Metallic Inclusions from Molten Steel through Filtration". *Current position*: Research Scientist, CSIRO, Australia.

Dallaire, François, M.Eng. Thesis, 1990, "Electric Sensing Zone Signal Behaviour in Liquid Aluminium". *Current position:* Ingenieur de projets, section d'instrumentation métallurgique, Bomem, Quebec.

Kuyucak, Selcuk, Ph.D. Thesis, 1989, "On the Direct Measurement of Inclusions in Molten Metals". *Current position:* Research Scientist, Canada Centre for Minerals and Energy Technology (CANMET), Ottawa, Ontario.

Nakajima, Hidemasa, Ph.D. Thesis, 1987, "On the Detection and Behaviour of Second Phase Particles in Steel Melts". *Current position: Board of Directors,*, Sumitomo Metal Industries Ltd., Japan.

Kim, Seon-Hyo, Ph.D. Thesis, 1987, "Physical Modelling of Liquid Phase Mass Transfer in Gas Stirred Ladle Processes". *Current position:* Associate Professor, Pohang Institute of Science and Technology, Korea.

Kulunk, Bahadir, M.Eng. Thesis, 1987, "Aqueous Modelling of Aluminum Wire Injection Procedures in Steelmaking"

Tanaka, Shigenori, Ph.D. Thesis, 1986, "Modelling Inclusion Behaviour and Slag Entrainment in Liquid Steel Processing Vessels". *Current position:* Senior Research Engineer, Nippon Steel Hikari Works, Japan.

Kuyucak, Selcuk, M.Eng. Thesis, 1986, "Direct Detection of Non-metallic Inclusions in Molten Iron".

Mazumdar, Dipak, Ph.D. Thesis, 1985, "Fluid Flow, Particle Motion and Mixing in Ladle Metallurgy Operations". *Current position:* Professor, Indian Institute of Technology, Kanpur, India.

Holford, W. David, M.Eng. Thesis, 1985, "A Measurement Technique for Refractory Erosion/Corrosion in Molten Metals". *Current position:* Materials Engineer, Pratt & Whitney Canada, Longueuil, Quebec.

Nakajima, Hidemasa, M.Eng. Thesis, 1985, "Modelling of Inclusion Behaviour in Liquid Metals". Current position; Board of Directors, Sumitomo, Japan.

Doutre, Don, Ph.D. Thesis, 1984, "The Development and Application of a Rapid Method of Evaluating Molten Metal Cleanliness". *Current position:* Senior Research Scientist, Novelis, Kingston, Ontario.

Perrin, René, Ph.D. Thesis, 1984, "Batch Annealing". *Current position:* Director of Research and Development, WestCast Industries, Brantford , Ontario.

Kadoglou, Antonios, M.Eng. Thesis, 1983, "Dissolution Kinetics of Powder Alloy Compacts in Liquid Aluminum".

Cameron, Ian, M.Eng. Thesis, 1982, "Low Temperature Modelling of Volatile Additions in Ironmaking". *Current position:* Stelco, Canada.

Argyropoulos, Stavros, Ph.D. Thesis, 1981, "Dissolution of High Melting Point Additions in Liquid Steel". *Current position:* Professor, Dept. of Metallurgy and Materials Science, University of Toronto.

Mucciardi, Frank, Ph.D. Thesis, 1980, "A Study of Light Alloy Addition Techniques in Steelmaking". *Current position*: Associate Professor, Faculty of Engineering, McGill University.

Ozberk, Engin, M.Eng. Thesis, 1980, "Vacuum Refining of Copper". *Current position:* Manager of Technology Development, Cameco Corporation, Port Hope, Ontario.

Tanaka, Masaaki, Ph.D. Thesis, 1979, "Hydrodynamics of Furnace/Ladle Tapping Operations". *Current position:* General Manager, Sumitomo Metal Industries Ltd., Japan.

Irons, Gordon, Ph.D. Thesis, 1978, "Kinetics of Desulphurization of Molten Iron by Magnesium Vapour". *Current position:* NSERC-Dofasco Professor, Dept. of Materials Science and Engineering, McMaster University, Hamilton, Ontario.

Gourtsoyannis, Loukas, Ph.D. Thesis, 1978, "Kinetics of Compound Gas Absorption by Liquid Iron and Nickel". *Current position:* President and Managing Director, MIRTEC S.A., Greece.

Mucciardi, Frank, M.Eng. Thesis, 1977, "Heat Flow to Cylinders Submerged in Liquid Metal Baths". *Current position:* Professor, Faculty of Engineering, McGill University.

Argyropoulos, Stavros, M.Eng. Thesis, 1977, "Kinetics of Ferroalloy Solution in Liquid Steel". *: Curr**ent** position:* Professor, Dept. of Metallurgy and Materials Science, University of Toronto.

Irons, Gordon, M.Eng. Thesis, 1975, "Magnesium Vapour Interactions with Molten Pig Iron". *Current position:* NSERC-Dofasco Professor, Dept. of Materials Science and Engineering, McMaster University, Hamilton, Ontario.

Henein, Hani, M.Eng. Thesis, 1975, "Hydrodynamics of Solid Additions to Liquid Steel". *Current position: Killam Fellow,* Professor, University of Alberta, Edmonton.

Storey, Anthony, M.Eng. Thesis, 1973, "Blast Furnace Oil Injection". *Current position:* Superintendent, Falconbridge Kidd Creek Mine, Ontario.

Chiesa, Franco, Ph.D. Thesis, 1972, "Natural Convection in Liquid Metals and Alloys". *Current position:* Professeur de Métallurgie, Cégep de Trois-Rivières, Quebec.

Solar, Maurice, Ph.D. Thesis, 1971, "Kinetics of Hydrogen and Carbon Monoxide Absorption by Stagnant Molten Iron". *: formerly* Project Manager, INCO Exploration and Technical Services Inc., Mississauga, Ontario., now private consultant.

Solar, Maurice, M.Eng. Thesis, 1969, "Diffusion of Hydrogen in Molten Iron".

Postdoctoral Fellows and Researchers Supervised

Iida Takamichi, 2004, Visiting Professor, "Physical Properties of liquid metals.
Reza Aboutalebi, 2003, Visiting Professor, "Electromagnetic flow control in single belt casting" (Teheran Science and Technology University).
Dr Ali Naji Meidani, 2002, Supersonic jet flows in top blowing steelmaking process (presently PDF).
Dr Donghui Li, 2003, Mathematical and physical modelling of single belt casting (presently PDF).
Dr Basim Kamal, 2001, Hardware and software development (Presently, Research Associate).
Dr H. Nogami, Visiting Fellow, Process Metallurgy, Japan Institute of Science Scholarship, 1997.
Dr J.-Y. Byun, Visiting Scholar from KIST (Korean Institute of Science & Technology), Non-Ferrous Process Metallurgy, 1997.
Dr Hussein Abuluwefa, Process Metallurgy Laboratory Administrator, 1997.
Dr M. Isac, Research Associate, Physical Metallurgy Professor, 1995-. Strip casting / steel processing,(Presently Research Manager McGill Metals Processing Centre).
Dr R. Sankaranarayanan, postdoctoral fellow, 1994-97. Ladle / tundish metallurgy.
Mr M. Tolvanen, visiting researcher, Rautaruukki Oy, Finland, 1994. Curved slab-casting computational studies.
Dr J. Kozinski, research associate, 1992; postdoctoral fellow, 1989-91. Slab reheating furnace technology.
Prof. M. Nilmani, visiting researcher, 1992. Pneumatic injection of particles into melts.
Prof. J. Jiang, visiting researcher, 1991-92. Iron and steelmaking.
Dr M. Hasan, research associate, 1990-91. Computational fluid dynamics.
Dr G. Carayannis, research associate, 1990-91. Data acquisition and process control.
Dr J.-W. Han, postdoctoral fellow, 1987-90. Tundish metallurgy.
Dr S. Joo, postdoctoral fellow, 1990. Tundish metallurgy.
Dr S. Kuyucak, postdoctoral fellow, 1989. Metal quality.
Mr N. Kurokawa, visiting researcher, 1987-88. Computational modelling of combined blowing reactors.
Dr J. Herbertson, postdoctoral fellow, 1986-87. Strip casting. *Current position:* Manager, Research New Technology Development, BHP Steel Newcastle Laboratories, Australia.

Dr D. Mazumdar, postdoctoral fellow, 1986-87. Ladle metallurgy.
Prof C. Xu, visiting researcher, Chongqing University, China, 1982-83. Thermal accretions ("mushrooms") in steelmaking.
Dr Y. Sahai, senior research associate, 1979-82. Ladle metallurgy. *Current position:* Professor, Dept. of Materials Science and Engineering, Ohio State University.
Mr D. Oymo, visiting researcher, 1982. Mixing studies in combination blowing.
Dr M. Salcudean, postdoctoral fellow, 1975-78. Computational fluid dynamics. *Current position: ret'd,, previously* Associate Vice-Principal, Research, University of British Columbia, Vancouver.

RESEARCH FUNDS AWARDED (1985-2005)

Project Title	*Source*	*Period*	*Average Amount/Yr*
Company donations in support of generic research program of MMPC	MMPC supporting companies	1995-2005	~120,000
Transport Phenomena in Metal Processing Systems	NSERC Operating Grant	2005-2010	100,000
Novel Metal Delivery and Cooling Systems for Strip Casting of Advanced Materials.	CFI	2002-2005	2,280,000
Full-Scale Water Modelling of Strip Casting of Ladle-Tundish-Mould Operations	NSERC, CRD Project	2002-2006	100,500
Novel Techniques for the Strip Casting of Advanced Materials	NSERC Strategic Project	2002-2006	120,000
Transport Phenomena in Metal Processing Operations	NSERC Operating Grant	2000-2005	95,000
Particle Image Velocimeter	NSERC Equipment Grant	2000	134,500
Development and Application of a Full-Scale Water Modelling Facility for Representing Steel Flows in Ladle-Tundish-Mould Operations	NSERC Collaborative Research and Development (CRD) Project	1998-2000	125,800
Advanced Metal Quality Measurement Systems	NSERC Strategic Grant	1996-99	90,000
Power Unit for Pilot Scale 300 lb Vacuum Induction Furnace for Steel Melts	NSERC Equipment Grant	1996-97	90,000
Transport Phenomena in Metal Processing Systems	NSERC Operating Grant	1995-99	77,200
Mathematical and Physical Modelling of Twin-Roll Casting Machines	NSERC Strategic Grant	1992-95	95,000
Transport Phenomena in Metal Processing Systems	NSERC Operating Grant	1992-95	82,000
Advanced Metal Quality Measuring Systems	NSERC Strategic Grant	1992-95	86,109
Intensively Stirred Reactor Systems	Nippon Steel Corporation	1992-94	15,000
Thin-strip Casting of Steels and Combination Blowing Simulations	Nippon Steel Corporation	1991-92	25,000
Sulphur/Carbon Determinator	NSERC Equipment Grant	1991-92	40,613
Transport Phenomena in Metal Processing Systems	NSERC Operating Grant	1989-92	67,000
Metal Quality Measurement Systems	NSERC Strategic Grant	1989-91	77,000
Modelling of Converter-based Smelting-Reduction Processes	American Iron & Steel Institute (AISI)	1989-91	100,000
Study of Liquid Aluminum-Atmosphere Reactions	Pechiney Corporation	1989-91	29,500
Twin-Roll Strip Casting	Nippon Steel	1989-90	10,000
Modelling Tundish Heat Sources	Aichi Steel	1989-90	18,000

Process Technology in Steel Reheating Furnaces	NSERC Cooperative Research & Development (CRD) Grant	1988-91	256,200
Modelling of Aluminum Holding Furnaces	Alcan Arvida	1988-90	35,250
Inclusion Sensor for Filtration of Steel	BHP Australia	1988-91	30,000
General Research - Steel, Aluminum	Industrial Sponsors (Alcan,BHP, Hi-Tech Ceramics, etc.)	1988-92	50,000
Combination Blowing in Steel Converters	Sumitomo Metal Industries	1988-90	18,500
Transport Phenomena in Metal Processing Systems	NSERC Operating Grant	1985-88	65,500
Optimization of Metallurgical Processes	NSERC Strategic Grant	1985-88	66,800

TEAM GRANTS AWARDED IN SUPPORT OF RESEARCH AND INFRASTRUCTURE
(R. Guthrie, Principal Investigator/Administrator and Director, MMPC)

Project Title	***Source***	***Period***	***Average Amount/Yr***
Modelling and Characterisation of Liquid Metal Processing and Casting Operations	FCAR Research team grant (Gruzleski, Guthrie, Mucciardi, Hasan, Chiesa)	2003-2006	78,000
Modelling and Characterisation of Liquid Metal Processing and Casting Operations	FCAR Research Team Grant (Gruzleski, Guthrie, Mucciardi, Hasan, Chiesa,, Drew)	2000-2003	88,000
McGill Metals Processing Centre	FCAR Research Centre Grant	1997-98	50,000
Measurement and Control of Metallurgical Processes, Simulation of Metallurgical Processes	FCAR Research Team Grant (Gruzleski, Guthrie, Mucciardi, Hasan, Chiesa,)	1997-2000	64,756
McGill Metals Processing Centre	FCAR Research Centres Program - Operating Grant (Gruzleski, Guthrie, Mucciardi, Hasan, Chiesa, Jonas, Yue, McQueen, Szpunar,Neale)	1993-96	190,000
McGill Metals Processing Centre	FCAR Research Centres Program - Equipment Grant	1993-94	65,800
McGill Metals Processing Centre	Industrial contributions - Canadian Steel Industry Research Association, BHP, Hatch Associates, Iscor Limited, Cray Research, Alcan, Hazelett Strip-Casting Corp.	1990-94	~200,000
Simulation, Measurement	FCAR Team Grant	1994-97	55,000

and Control of Metallurgical Processes			
Simulation, Measurement and Control of Metallurgical Processes - Equipment Grant	FCAR Team Equipment Grant	1994-95	8,500
Études cinétiques des métaux en phase liquide	FCAR Team Grant	1991-94	56,866
Études cinétiques des métaux en phase liquide - Equipment Grant	FCAR Team Equipment Grant	1991-92	11,000
Mathematical and Physical Modelling of Metallurgical Processes	Ministère de l'Enseignement supérieur et de la Science	1988-91	204,725
Liquid Metal/Casting Processing Centre	NSERC Infrastructure Group Grant	1988-91	42,333