

Essential Readings in **Light Metals**

VOLUME 2

*Aluminum Reduction
Technology*

Edited by
Geoff Bearne, Marc Dupuis and Gary Tarcy

TMS

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PREFACE

This Aluminum Reduction Technology volume in the *Essential Readings in Light Metals* collection has been created to give people with an interest in the industry, whatever their level of expertise, easy access to a tremendous body of knowledge that exists in The Minerals, Metals & Materials Society's annual *Light Metals* proceedings publications.

It is incredible to think that around 1,500 papers have been published on aluminium reduction technology subjects in *Light Metals*. The 1962 AIME International Symposium on the Extractive Metallurgy of Aluminum, held in New York, started the ball rolling and the conference has been held annually since 1971. The proceedings publication adopted the title *Light Metals* that year. This collection of papers represents the editors' best efforts to choose the most influential papers on aluminum reduction technology published in the *Light Metals* volume. As such, it draws from papers from 1963 and from the period 1971 to 2011 inclusive (proceedings were not published in the other years). The collection therefore spans almost 50 years of development.

We have selected 162 papers for this book and, although forming a large volume, it represents only 11% of the available material. The resulting collection, while comprehensive, is a mere starting point and we have referenced 256 additional papers in the recommended reading lists at the end of each section.

For convenience the editorial team has categorized the papers into seven main aluminium reduction technology themes:

1. Fundamentals
2. Modeling
3. Design
4. Operations
5. Control
6. Environmental
7. Alternative processes

The first six themes deal with aspects of conventional Hall-Héroult electrolytic reduction technology, whereas the last theme has papers on nonconventional processes. Papers relating specifically to cathodes and anodes (including inert anode technology) can be found in the Electrode Technology volume (Volume 4 of the *Essential Readings in Light Metals* collection). To avoid excessive bias toward particular themes, the numbers of papers selected in each theme reflect roughly the distribution found in the annual *Light Metals* volume. For example, approximately 23% of papers in the annual proceedings relate to reduction fundamentals and so that proportion is mirrored in this book.

For ease of reference, the papers in each of the seven sections have been clustered by sub-themes. Please refer to the table of contents (pages v-xvi) to help find papers on your specific topics of interest.

This volume has the following objectives:

- Give a knowledge boost to those who are new to the industry
- Provide a reference for those who are tackling a given problem and want to know what has been done in the past on that particular issue
- Give a historical progression of technology development
- Cover all key areas of the relevant technology

The editorial team has been guided by the following selection criteria:

- Papers that described breakthroughs in the science
- Papers that have had a big impact on the industry
- Review papers that bring together the current (at the time) thinking on key topics and that have stood the test of time
- Papers rated highly by peers for their importance and influence and supported, where appropriate, by citations and best paper awards

The assistance of the other members of the editorial team (whose names are given below) in the screening and selection of papers was indispensable. We express our high appreciation for their efforts.

- John Chen
- Halldór Guðmundsson
- Nancy Jorunn Holt
- Margaret Hyland
- Pascal Lavoie
- Ketil Rye
- Alton Tabereaux
- Jayson Tessier
- Xiangwen Wang

We recognize that no attempt to create a collection such as this can be perfect because of the subjectivity of the paper selection process. Other teams might have chosen some different papers. However, the editors believe that this volume contains the cream of the *Light Metals* reduction papers from the last five decades and, as such, it is a valuable resource.

Geoff Bearne

Marc Dupuis

Gary Tarcy

Lead Editors

LEAD EDITORS



Geoff Bearne

Geoff Bearne has worked in the aluminum industry for more than 30 years. He graduated in engineering from the City University (London) and worked initially in the electrical power industry. He was employed by Dubai Aluminium Limited for eight years from 1981 and then joined Rio Tinto's aluminium product group at their research center in Melbourne, Australia. Over a 22 year period in Australia, Geoff held a number of leadership roles, concluding as General Manager of the research center. During this period he led the development and transfer of CD200 reduction cell technology. Since the acquisition of Alcan by Rio Tinto in 2007, Geoff has held senior management roles with Rio Tinto Alcan, including Director of Primary Metal Technology and R&D, based in Voreppe, France. He is currently General Manager, Technology Delivery Systems with Rio Tinto Technology and Innovation. Geoff has published 16 papers and was editor of *Light Metals 2009*.



Marc Dupuis

Marc Dupuis is a consultant specializing in the applications of mathematical modeling for the aluminium industry since 1994, the year when he founded his own consulting company, GeniSim Inc. Before that, he graduated with a Ph.D. in chemical engineering from Laval University in Quebec City in 1984, and then worked for 10 years as a research engineer for Alcan International. His main research interests are the development of mathematical models of the Hall-Héroult cell dealing with the thermoelectric, thermomechanic, electromagnetic, and hydrodynamic aspects of the problem. He was also involved in the design of experimental high amperage cells and the retrofit of many existing cell technologies.



Gary Tarcy

Gary Tarcy is the Manager of Smelting R&D at Alcoa Technical Center, New Kensington, Pennsylvania, USA. Gary has worked for Alcoa for 34 years. He holds 26 patents and has published 31 papers. In 1986 he was the winner of the Alcoa Chapter of Sigma Xi best technical paper award and in 2000 the winner of Alcoa's Arthur Vining Davis Award for Technical Excellence. In 2005 he was the winner of the TMS Light Metals Award for best paper. In 2011 he won the TMS Light Metals Award for the best paper for the second time and also won the Professor Barry Welch Best Paper at the 10th Australasian Smelting Technology Conference. In 2006 he was the winner of the alumni of the year from the Department of Chemistry. Only six such awards have ever been given. Gary is also an invited lecturer for the TMS Industrial Electrolysis course and has been an invited lecturer at several of the Australasian Aluminum Smelting and Technology Conferences. Gary holds both B.S. and M.S. degrees in chemistry from Bowling Green State University where he specialized in the study of electrochemistry and photo-electrochemistry.

EDITORIAL TEAM



John Chen

John J.J. Chen is a professor with the Chemical and Materials Engineering Department at the University of Auckland where he also earned his Ph.D. in engineering in 1980. He has won the TMS Best Reduction Technology Paper Award (1992, 1993, and 1996) and has been on the TMS Light Metals Division Council and the Aluminum Committee. John is a Fellow of the Institute of Chemical Engineers (UK), Institute of Professional Engineers New Zealand, and the Royal Society of New Zealand. He has worked in an aluminum smelter for three years, and has been an academic for more than 30 years, with eight of those (1996–2004) as the Head of the Department of Chemical and Materials Engineering, University of Auckland. He has published over 270 papers in international journals and conference proceedings, and more than 60 proprietary technical reports. His current research includes a number of areas in aluminium smelting technology and decision science as it applies to process control.



Halldór Guðmundsson

Halldór Guðmundsson was awarded a B.Sc. in Physics from the University of Iceland in 1986 and an M.Sc. in Materials Science from the University of Virginia, USA, in 1989. He was a metallurgist for nine years at the Innovation Center of Iceland, working in the field of applied research, testing, and consulting. Halldór joined Nordural in 1998 as laboratory manager responsible for cast house quality control and environmental management. He moved to electrolysis in 2004 as a process engineer with emphasis on process control, alumina, and anode quality. He has been technical manager of reduction since 2009 and has been a lecturer at the Mechanical Engineering Department of the University of Iceland since 1992. He achieved a Master of Engineering Studies in Aluminium Reduction Technology from the University of Auckland in 2009.



Nancy Jorunn Holt

Nancy Jorunn Holt is currently Manager External R&D for Primary Technology in Hydro Aluminium and looking after academic involvements in support of Hydro's technology developments beyond HAL4e and operation support for primary production. She has been with Hydro since 1991 and earlier worked on development for the electrolysis, specializing in mathematical modeling and environment topics. She has contributed to TMS as both author and session chair on several occasions. Nancy has also, for 10 years, been involved in several major smelter improvement programs, mainly as project manager.



Margaret Hyland

Margaret Hyland is a Professor in the Department of Chemical and Materials Engineering, University of Auckland, and Associate Director of the Light Metals Research Centre. Margaret's expertise is in environmental performance, especially fluoride emissions and their capture, as well as design and performance of carbon materials. Margaret has worked with major aluminum producers and suppliers for the past 20 years. She is a four-time winner of the TMS Light Metals and Carbon Awards. Margaret established the successful postgraduate certificate and masters programs in Light Metals Reduction Technology offered by the Light Metals Research Centre, providing advanced training aluminum reduction technology. Margaret has authored over 250 refereed publications and technical reports.



Pascal Lavoie

Pascal Lavoie obtained his bachelor's degree in Materials and Metallurgical Engineering from Université Laval, Québec, Canada. He joined Noranda's Magnola magnesium smelter as process engineer. When Magnola was curtailed, he moved to Noranda New Madrid smelter as metallurgical process engineer and obtained a Lean Six Sigma Black Belt certification. In 2006, Pascal joined the Light Metals Research Centre of the University of Auckland as Manager – International projects. He led

a team conducting more than 40 industrially based R&D projects. Since 2011, Pascal has also been Chief Engineer of the Centre. In 2006, he received the TMS Light Metals Division Young Leader award and has been on the LMD council and various committees since.



Ketil Rye

Ketil Rye was awarded an M.Sc. in Metallurgy from the Norwegian University of Technology, Trondheim, in 1987. He completed a Ph.D. in Electrochemistry from the same university in 1992. Ketil was a Research Scientist with SINTEF Materials Technology in Norway from 1992 to 1994; a Smelting R&D Engineer with Elkem Aluminium Mosjøen, Norway, from 1994 until 2001; and then Smelting R&D Manager with Elkem Aluminium Mosjøen until 2008. Subsequently he was Technical Director with Elkem Aluminium and, since 2009, has been Production Manager at Alcoa Mosjøen, Norway.



Alton Tabereaux

Alton Tabereaux has been a technical consultant in resolving issues and improving productivity at aluminum smelters since 2007. He graduated with a Ph.D. in Inorganic Chemistry from the University of Alabama in 1971. He then worked for 33 years as a Technical Manager of Research and Process Technology for both Reynolds Aluminum and Alcoa Primary Metals. In 1994 and 2000 Alton was recipient of the *JOM* Best Technical Paper Award. He was the editor of *Light Metals 2004* and received the TMS Light Metals Distinguished Service Award in 2007 and the TMS Technology Award in 2008. Alton has been a lecturer at the annual Carnegie Mellon University Aluminum Electrolysis Course/TMS Industrial Aluminum Electrolysis Courses since 1985, the Australasian Aluminum Smelting and Technology Conferences since 1989, and the annual International Course on Process Metallurgy of Aluminium held in Trondheim, Norway since 1991. He has published over 65 technical papers and obtained 17 U.S. patents in advances in the aluminum electrolysis process.



Jayson Tessier

Jayson Tessier earned his Ph.D. in 2010 from Université Laval, Quebec City, Canada, in chemical engineering and is currently a staff research engineer at Alcoa within the Global Primary Metal Technology Development group. Jayson is mainly involved in the optimization of reduction cell performance through the reduction of process variation. Over the years, Jayson has contributed to TMS and other international conferences and journals through the submissions of technical papers since 2004. With other Alcoa colleagues, Jayson was the recipient of the Professor Barry Welch Best Paper Award at the 10th Australasian Smelting Technology Conference.



Xiangwen Wang

Xiangwen Wang, a technical specialist and veteran in aluminum reduction technology, is currently a Technology Program Manager at the Alcoa Global Primary Metal Technology Development group. He has worked in the aluminum industry for 24 years. He obtained both his B.S. and M.S. in Non-Ferrous Process Metallurgy from Northeast University, China, and his Ph.D. in metallurgy from Colorado School of Mines. He joined Reynolds Metals in 1988, and now at Alcoa specializes in aluminum reduction with the areas of interest in molten salt chemistry, electrochemistry, advanced measurements and applications in smelting cells, laboratory R&D, and technology transfer and deployment in production plants. Xiangwen was one of the pioneers in developing and deploying slotted anode technology across smelters, and most recently he invented, developed, and deployed the STARProbe™ system which instantly measures cryolite electrolyte properties real-time in potrooms. He holds numerous patents and has many publications. He was a two-time winner of the TMS Light Metals Award for best paper in 1991 and 2011 and also was a co-recipient of the Professor Barry Welch Best Paper at the 10th Australasian Smelting Technology Conference.