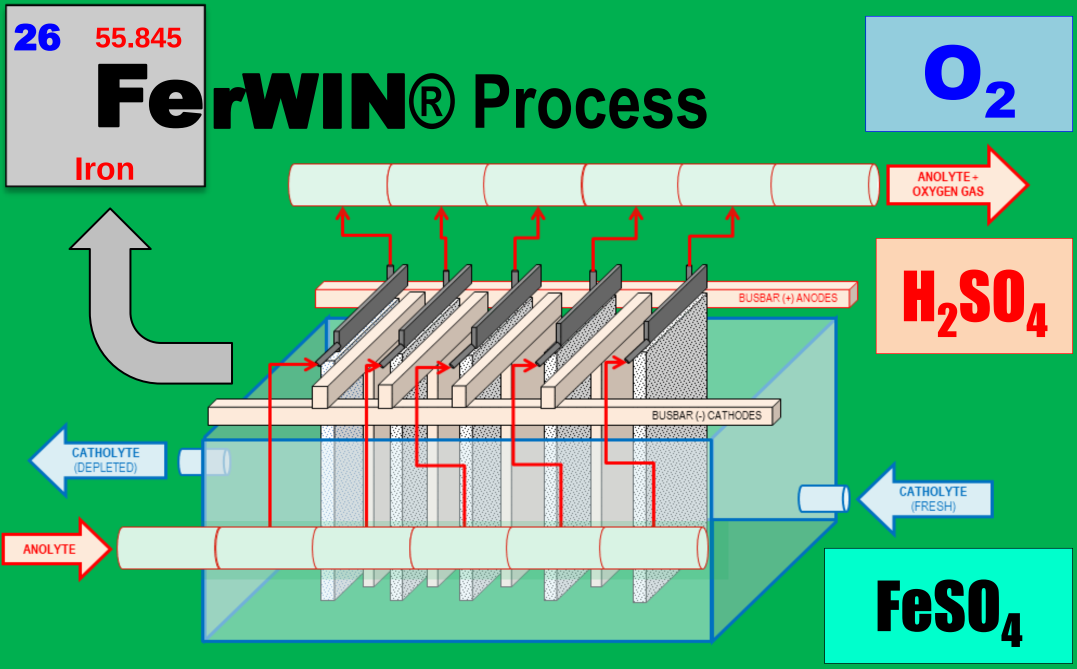
François Cardarelli

Electrowinning Iron and Recycling Sulfuric Acid from Iron Sulfates: A Zero-Carbon Iron-Making Process



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Units Policy

In this monograph all the units of measure used for describing physical quantities and properties were those recommended by the *Système International d'Unités* (SI) except in some few instances where some units from the *US Customary System* (USCS) are used in conjunction. For accurate conversion factors between these units and the other non SI units (e.g., cgs, fps, Imperial, and US customary systems) please refer to the reference book of the same author:

CARDARELLI, F. (2005) *Encyclopaedia of Scientific Units, Weight and Measures. Their SI Equivalences and Origins*. Springer, New York, London, xxiv, 848 pages; ISBN 978-1-85233-682-0.

Books by the same author:

CARDARELLI, F. (2022) *Sulfuric Acid Digestion, Sulfuric Acid Baking, and Sulfation Roasting in Mineral and Chemical Processing, and Extractive Metallurgy*. Electrochem Technologies & Materials Inc., Montreal, Canada, xvi, 285 pages, 93 tables, 76 black and white figures. ISBN 978-1-7775769-0-5.

CARDARELLI, F. (2018) *Materials Handbook. A Concise Desktop Reference, Third edition*. Springer, Cham, London, New York. cxxxii, 2254 pages, 150 black and white figures, 25 illustrations in color in two volumes. ISBN 978-3-319-38923-3.

CARDARELLI, F. (2008) *Materials Handbook. A Concise Desktop Reference, Second edition*. Springer, London, xxxviii, 1340 pages, 55 figures; ISBN 978-1-84628-689 (Out-of-Print).

CARDARELLI, F. (2005) *Encyclopaedia of Scientific Units, Weight and Measures. Their SI Equivalences and Origins*. Springer, New York, London, xxiv, 848 pages; ISBN 978-1-85233-682-0.

CARDARELLI, F. (2000) *Materials Handbook. A Concise Desktop Reference*. Springer, London, New York, ix, 595 pages, 7 figures; ISBN 978-1-85233-168-2 (Out-of-Print).

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CARDARELLI, F. (1997) *Scientific Unit Conversion. A Practical Guide to Metrication*. Springer, London, Heidelberg, xvi, 456 pages, ISBN 978-3-540-76022-9 (Out-of-Print).

Author Biography

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Canadian & French citizen

Academic Background

Ph.D. (Doctorat), Chemical Engineering (Université Paul Sabatier, Toulouse, 1996)

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DEST (Credits) in Nuclear Sciences and Technologies (CNAM, Paris, 1988)

DEUG B in Geophysics and Geology (Université Pierre et Marie Curie, Paris, 1987)

Baccalaureate C (Mathematics, Physics, and Chemistry) (CNED, Versailles, France, 1985)

Working Areas

The author has worked in the following areas since 1990 until present:

2010-Present President and owner, Electrochem Technologies & Materials Inc., Montreal (Quebec), Canada, manufacturing industrial electrodes and electrolyzers, producing vanadium, tantalum, and tungsten chemicals, inventing, patenting, and commercializing electrochemical, chemical, and metallurgical processes for recycling by-products.

2008-2010 Recycling manager, 5N Plus Inc., Ville Saint-Laurent (Quebec), Canada, in charge of the recycling of end-of-life cadmium telluride (CdTe) thin-film photovoltaic solar panels and the hydrometallurgical recovery of tellurium and cadmium.

2007-2008 Principal electrochemist, Materials and Electrochemical Research (MER) Corp., Tuscon (Arizona), USA, working on the electrowinning of titanium metal powder from composite Ti_2OC anodes in molten salts, and other materials-related projects.

2000-2007 Principal chemist (materials), technology department, Quebec Iron and Titanium (QIT) now Rio Tinto, Sorel-Tracy (Quebec), Canada, invented the electrowinning of titanium metal from molten titanium slags and on other novel electrochemical processes.

1998-200 Materials expert and industrial electrochemist, lithium department, Avestor (now Blue Solutions), involved in the metallurgy and processing of lithium metal anodes and the recycling of spent lithium metal polymer batteries.

1997-1998 Battery product leader, technology department, Argotech Productions, Inc. (Avestor), Boucherville (Québec), Canada, in charge of electric-vehicle, stationary, and down-hole oil-drilling applications of lithium metal polymer batteries.

1996-1997 Registered consultant in chemical and electrochemical engineering (Toulouse, France) providing scientific advices on electrochemical processes and electrode materials.

1993-1996 Research scientist, Laboratory of Electrochemical Engineering (Université Paul Sabatier, Toulouse, France) for the electrodeposition of tantalum in molten salts and the preparation and characterization of iridium-based industrial electrodes for oxygen evolution in acidic media (sponsored by Electricité de France).

1992-1993 Design engineer, Institute of Marine Biogeochemistry (CNRS & École Normale Supérieure, Paris, France) for the environmental monitoring of heavy-metal pollution by electroanalytical techniques and by alpha spectrometry.

1990-1992 Research scientist, Laboratory of Electrochemistry (Université Pierre & Marie Curie, Paris, France) for the development of a beta nuclear scintillation detector used for electrochemical experiments involving radiolabelled compounds.

"Nothing is too wonderful to be true if it be consistent with the laws of nature."

Michael Faraday (1791-1867)

"Il y a une analyse selon laquelle, d'une vérité compacte, on déduit des vérités plus simples."

André-Marie Ampère (1775-1836)

"Ogni metallo ha un determinato potere, diverso da metallo a metallo, di mettere in moto il fluido elettrico."

Alessandro Volta (1745-1827)

"Connaître, découvrir, publier, tel est le destin d'un scientifique."

Dominique François Jean Arago (1786-1853)

Preface

This comprehensive monograph is primarily intended to describe the patented FerWIN® technology, a green and zero-carbon iron-making process, which consists to perform the electrowinning of iron metal and the recycling of sulfuric acid from iron sulfates that are by-produced at the million tonnes scale worldwide while releasing pure oxygen gas.

The information has been presented in such a form that industrial electrochemists, chemical engineers, metallurgists, and other practicing engineers, scientists, professors, and technologists will have access to relevant scientific and technical information supported by key experimental data that were obtained from extensive laboratory, prototype, and pilot testing. It also includes comprehensive electrochemical and engineering calculations, costs and benefits analysis, a financial and sensitivity analysis.

I hope this monograph will be of value also to men and women engaged in the traditional iron and steelmaking industries that want to understand this novel electrochemical approach outside their conventional blast furnace, direct reduced iron, and electric arc smelting processes.

Finally, the monograph may be of interest to persons in the steelmaking industries occupying managerial positions such as chief executives, chief operating officers, and V.P. of operations.

Montréal, Québec, Canada François Cardarelli, November 2023

Dedication

I dedicate this monograph to my late mother Claudine, my father Antonio who together with my late uncle Consalvo supported me in the early 1980s in establishing a basic mineralogical, chemical, and metallurgical laboratory, and scientific library and to Louise St-Amour for her continuous support and understanding during all these years.

Acknowledgements

I want to express my deepest thanks to the companies in North America, South America, Europe, and Asia who tested and assessed the patented electrochemical process over the last decade and supplied various feedstocks originating from their commercial operations.

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Dr. François Cardarelli, President and Owner of the Canadian company *Electrochem Technologies & Materials Inc.*, is an industrial chemist with a strong physical-chemistry background and a doctorate in chemical engineering from the University Paul Sabatier (UPS) Toulouse III. He is the inventor and co-inventor of 16 patents, and the sole author of three reference handbooks published worldwide by Springer since 1996 and two monographs.

He has over 34 years of industrial experience in North America and Europe in developing electrochemical, chemical, and metallurgical processes for winning, refining or producing a variety of metals, alloys, and inorganic chemicals either from aqueous solutions or molten salts media.

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Dr. François Cardarelli is a member in good standing of the following professional organizations and societies: *American Institute of Chemical Engineers* (AIChE)[Lifetime member], *American Chemical Society* (ACS), *Chemical Institute of Canada* (CIC), *Canadian Society for Chemical Engineering* (CSChE), *The Electrochemical Society* (ECS), *Mineralogical Society of America* (MSA), *Ordre des Chimistes du Québec* (OCQ), The *Oughtred Society* (OS), and *The Minerals, Metals and Materials Society* (TMS).

François Cardarelli

Electrowinning Iron and Recycling Sulfuric Acid from Iron
Sulfates: A Zero-Carbon Iron-Making Process

This comprehensive monograph is primarily intended to describe the patented FerWIN® technology, a green and zero-carbon iron-making process, which consists to perform the electrowinning of iron metal and the recycling of sulfuric acid from iron sulfates that are by-produced at the million tons scale worldwide while releasing pure oxygen gas.

The information has been presented in such a form that industrial electrochemists, chemical engineers, metallurgists, and other practicing engineers, scientists, professors, and technologists will have access to relevant scientific and technical information supported by key experimental data that were obtained from extensive laboratory, prototype, and pilot testing. It also includes comprehensive electrochemical and engineering calculations, costs and benefits analysis, financial and sensitivity analysis.

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- Industrial electrowinning plant calculations;
- Prototype and pilot testing;
- Costs and benefits analysis;
- Financial and sensitivity analysis;
- Implementation strategy;
- Bibliography;
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