SAIMM PYROMETALLURGY
INTERNATIONAL CONFERENCE 2026
Foundations of Competitiveness and Sustainability

26-28 MAY 2026
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THE SOUTHERN AFRICAN INSTITUTE OF MINING AND METALLURGY

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FOREWORD

What will South African pyrometallurgy be a hundred years from now?
What foundations must we lay now to get there?
Are we willing to make the choices that will change the future of our industry – and our country?

These are the questions behind this conference — and behind these proceedings.

South Africa possesses the geological endowment, the people, and a century of built industrial capability to grow beyond pyrometallurgy, to explore and tame the vast and daunting frontier of high-temperature science and technology. The minerals beneath the Bushveld Complex — chromite, platinum group metals, vanadium, titanium — and the manganese of the Kalahari Manganese Field occur in concentrations found nowhere else on earth. They are the feedstocks of traditional smelting and, increasingly, the critical minerals of the energy transition: PGMs for hydrogen fuel cells, vanadium for grid-scale energy storage, titanium and manganese for the advanced materials a changing world demands.

This conference is an opportunity to look back at where we came from, acknowledge where we are now, and most importantly, look into the future and start choosing who and what we want to be. We invite our international colleagues — from 14 countries — to shape this future with us. Pyrometallurgy is in our soil, in our people, and in our story.

A century ago, Hendrik van der Bijl laid three foundations for a minerals-based industrial economy: affordable electricity through the Electricity Supply Commission, domestic steel through the Iron and Steel Corporation, and development capital through the Industrial Development Corporation. On those foundations rose the ferroalloy smelters of the 1960s, Mintek's DC arc furnace technology — developed here and licensed to the world — the ilmenite smelters of Namakwa Sands and KZN Sands, and the platinum smelting complexes of the Bushveld. Van der Bijl built with vision, with principle, and without self-enrichment. He planted trees under whose shade he would never sit. Politics change. Principles endure.

Those foundations served this country for a hundred years. Today South Africa's pyrometallurgical industry is no longer competitive or sustainable. Electricity costs have increased more than ninefold since 2008. Infrastructure constraints limit what we can move and produce. The global production landscape has shifted decisively — China now supplies approximately 60% of the world's ferrochrome, a position built through sustained state investment, and colleagues across Europe, Asia, and the Americas face variants of the same competitive pressure. These facts are the springboard for what comes next. Foundations can be laid again — and laying them will require choices that are bound to challenge accepted assumptions and norms, both within our industry and beyond it. This conference is a first foundation stone.

For the first time, the SAIMM brings Pyrometallurgy, Furnace Tapping, and Refractories together under a single banner — three symposia in one gathering. This is a deliberate consolidation of disciplines that share operating pressures, that depend on each other technically, and that are stronger for working in the same room. Ex Unitate Vires. The conference structure carries a message to our industry and our country: unity is strength. This time, all of us.

The programme reflects a community that is already choosing. One hundred and four papers from 14 countries. Four plenaries, fifteen keynotes, ten invited presentations, and sixteen student papers span the full arc from seasoned industrial practice to the next generation's fresh contribution. The PyroFuZA workshop — the Future of Pyrometallurgy in South Africa — opens the conference week with the forward-looking question that matters most: who do we choose to become?

Among the international colleagues gathered here are partners whose own industries face overlapping pressures. They bring perspectives that no single national community could generate alone.

The next generation is here too — and their presence carries a question about whether this industry will build the conditions that retain its best young minds or continue to export them Van der Bijl laid foundations for competitiveness and sustainability that carried this industry for a century. We have the endowment, the people, and the knowledge to lay new foundations, built on competitive energy, principled leadership, strategic partnerships, and the courage to invest in a future whose full benefit our children's children will inherit. These proceedings can be the first planting.

Let us choose well … together.

Dr Johan Zietsman
Conference Chairman

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Dr Johan Zietsman

CEO

Ex Mente Technolgies

Johan is an experienced metallurgical engineer, skilled in pyrometallurgy, thermochemistry, computational modelling and consulting in a wide range of commodities such as iron and steel, high-titania slag, ferrochrome, ferromanganese and platinum group metals. Through his software engineering skills and experience, he contributes to system design and implementation solutions for clients. Johan leads the Ex Mente team and supervises a number of postgraduate students at the University of Pretoria.

Symposium Chairperson

Dr Izak Cameron

Research and Development Scientist
Elkem ASA

Izak Cameron is a Research and Development Scientist at Elkem ASA, focusing on refractory solutions for pyrometallurgical processes. He earned his PhD in Metallurgical Engineering from the University of Pretoria, specializing in tap-hole clay behavior and binder systems. With extensive experience in refractory product development and process optimization, Izak drives innovation through microsilica-based technologies and sustainable high-temperature solutions. He is passionate about knowledge transfer and translating research into practical applications that enhance performance and efficiency in the metals industry.

Symposium Chairperson

Prof. Andrie Garbers-Craig

University of Pretoria

Andrie holds an SM (Metallurgy) from the Massachusetts Institute of Technology (MIT) and a PhD (Metallurgy) from the University of Pretoria. She began her career at Mintek, South Africa, where she was involved in both fundamental and applied pyrometallurgical research. In 1995, she joined the R&D division of Iscor (Iron and Steel Corporation of South Africa) before transitioning to academia in 1999. She is currently a full professor in the Department of Materials Science and Metallurgical Engineering at the University of Pretoria, where her research focuses on pyrometallurgical processes and refractory materials. She holds the Valterra Platinum Chair in Pyrometallurgy.

Plenary Speakers

Dr Stefan Swanepoel

Group Innovation & Strategy Manager
Samancor Chrome

Stefan holds an MBA from the University of the Witwatersrand and a PhD from the University of Pretoria. He has nearly two decades of experience in the ferrochrome industry, working across both pre-reduction and pre-oxidative sintering technologies, as well as submerged-arc and DC-arc furnace operations. Since joining Samancor Chrome in 2014, he has played a key role in techno-economic modelling to support major acquisitions and in the technical integration of new operations into the Samancor portfolio. Stefan currently serves as Group Innovation and Strategy Manager, where he guides and supports Samancor's smelting business units in addressing operational and technological challenges.

Rodney Hundermark

Head of Smelting Technology
Valterra Platinum

Rodney has extensive experience within the pyrometallurgical industry, having worked on the Anglo American Platinum, Anglo American and now Valterra Platinum smelting operations since 1999. He has held various operational roles up to 2006, and thereafter several process engineering roles, and now currently holds the role of Head of Smelting Technology. His expertise is mostly focused on the Platinum Group Metals (PGM) smelting industry within Southern Africa, however, also extends to nickel laterite and sulphide copper smelting. He has in-depth technical knowledge and operational management experience on electric furnaces, flash furnaces and matte converting operations, and the associated unit operations. He has considerable project experience from concept stage through to execution, and subsequent ramp-up and optimization.

Dr Lloyd Robert Nelson

Director
Pyro One (Pty) Ltd

Professional Qualifications and Memberships:
- Over 40 years' experience in applied research and technology development, operations, and consulting in the metallurgical industry
- Registered Professional Engineer (ECSA) since 1988
- B.Sc. and M.Sc. Metallurgical Engineering degrees from the University of the Witwatersrand
- Ph.D. in Metallurgical Engineering, University of Missouri-Rolla (now Missouri University of Science and Technology).
- Fellow of Southern African Institute of Mining & Metallurgy (SAIMM), Member of Association for Iron and Steel Technology (AIST) and Member of The Minerals, Metals & Materials Society (TMS).

Professional Work Experience:
- Independent Consultant, Director Pyro One (Pty) Ltd, based in South Africa (since 2022)
- Head of Smelting and Refining Technology, Anglo American Platinum Ltd + Lead Pyrometallurgy, Technical & Sustainability, Anglo American (2007-2022)
- Practice Leader, Pyrometallurgy – Africa, Hatch (2001-2007)
- Technology Manager, Chrome, Samancor Chrome, (2001)
- West Plant/NST JV Plant Manager, Tubatse Ferrochrome (1998-2001)
- Billiton/Gencor Process Research, Manager, Chromium R&D Department (1994-1998)
- Doctoral Candidate, Graduate Teaching & Research Assistant, US Bureau of Mines Generic Mineral Technology Center for Pyrometallurgy, Univ. of Missouri-Rolla (1991-1994)
- Senior Engineer, Pyrometallurgy Division, Mintek (1985-1991).

Dennis Montaque Brazier

Managing Director
Refractory and Metallurgical Solution Pty Ltd

Dennis Montaque Brazier is a seasoned metallurgical leader and entrepreneur with more than 30 years of international experience across Africa, Europe, and the Middle East. Trained as an extractive metallurgist, he has held senior operational and executive roles in copper, zinc and refractory industries, combining deep technical expertise with commercial and strategic leadership.

He began his career at Mintek, contributing to pioneering plasma smelting technologies, before moving into production and leadership roles at Palabora Mining Company under Rio Tinto. Rising to General Manager Copper Processing, Dennis led a division of 800 staff, driving record production, executing major shutdowns, and enhancing profitability, safety, and customer value. His commercial expertise was sharpened as Marketing Manager, where he secured favourable concentrate contracts and strengthened customer relationships.

Internationally, Dennis served as Managing Director of Union Copper Rod in Abu Dhabi, where he successfully commissioned the largest copper rod mill in the Middle East and established long-term supply agreements across the Gulf and Asia. Returning to South Africa, he guided Vereeniging Refractories through restructuring as COO and CEO, implementing efficiency programs, safety improvements, and technical-driven marketing strategies.

In 2012, Dennis co-founded and became Managing Director of Refractory and Metallurgical Solutions (RMS). He has also consulted extensively for companies such as Glencore, Palabora Copper, Union Copper Rod and SPMP Oman, advising on smelting, refractory performance, and operational optimisation.

A Fellow of the Southern African Institute for Mining and Metallurgy, Dennis has complemented his technical foundation with executive training at Duke University and UNISA. Known for his integrity and collaborative leadership style, he is passionate about mentoring young professionals and building high-performing, multicultural teams.

Keynote Presenters

Rodney Jones

Consulting Pyrometallurgist
Pyro Consulting

Rodney Jones is a consulting chemical engineer and metallurgist with more than 40 years of pyrometallurgical experience in a wide variety of processes that have been taken from concept to industrial implementation. Rodney is a Past President and an Honorary Life Fellow of the Southern African Institute of Mining and Metallurgy (SAIMM). Rodney was employed for thirty seven years in the Pyrometallurgy Division at Mintek - where he worked as a Senior Technical Specialist. For the past six years, he has worked as an independent Consulting Pyrometallurgist. Rodney holds a BSc(Eng) degree in chemical engineering from the University of the Witwatersrand (Wits) in Johannesburg, a BA degree in logic and philosophy from the University of South Africa, and MSc(Eng) and PhD degrees in metallurgical engineering from Wits University.

Wynand Steyn

Dean of the Faculty of Engineering
University of Pretoria

Prof Wynand Steyn is Dean of the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria. He is a professionally registered civil engineer with a research interest in pavement engineering and materials, vehicle-pavement interaction, accelerated pavement testing, Civiltronics and instrumentation. He completed his undergraduate and graduate studies at the University of Pretoria, South Africa. He authored, co-authored and edited 62 journal papers, 23 book chapters (author/co-author/editor) and 118 conference papers.

He is an Associate Editor of the International Journal for Pavement Engineering and has a B2 National Research Foundation (NRF) rating. He is a Fellow of the South African Institution of Civil Engineers and a fellow of the South African Academy of Engineering (SAAE).

Dr Johan Zietsman

CEO
Ex-Mente

Johan is an experienced metallurgical engineer, skilled in pyrometallurgy, thermochemistry, computational modelling and consulting in a wide range of commodities such as iron and steel, high-titania slag, ferrochrome, ferromanganese and platinum group metals. Through his software engineering skills and experience, he contributes to system design and implementation solutions for clients. Johan leads the Ex Mente team and supervises a number of postgraduate students at the University of Pretoria.

Chris Hattingh

Executive Director
Centre For Risk Analysis (CRA)

With a special focus on trade, investment, and economic matters, as well as foreign policy, Chris serves on the Executive Board of the Global Trade and Innovation Policy Alliance, sits on the advisory council of the Initiative for African Trade and Prosperity and holds the position of Senior Fellow at African Liberty. Chris holds an MPhil (Business Ethics) degree from Stellenbosch University. In his role at the CRA, Chris leads strategic engagements and briefings to clients across South Africa, as well as globally.

Eli Ringdalen

Senior Research Scientist
SINTEF

MSc. in ore geology from NTNU, Norway in1979. PhD in Metallurgy at NTNU, Norway in 1999. Subject of PhD thesis was HCFeCr process. Worked in various mining and metallurgical companies including Mn-alloy and silicon plants until 2006. From then working at SINTEF with projects within FeSi and Si, Mn-alloys, HCFeCr, as well as with environmental challenges, CO_2 emissions and development of new process, especially based on gas- metal reactions . Main research field: pyrometallurgi, ores, quartz, carbon and biocarbon reductants, use of gases, H_2 and CH_4 in metal production.

Dr Muxing Guo

Senior Research Expert
KU Leuven

Dr. Muxing Guo is a Senior Research Expert in the Department of Materials Engineering at KU Leuven, Belgium. With more than 40 years of experience, he has devoted his career to scientific research, teaching, and industrial applications in the field of materials science and metallurgy. His work spans both fundamental and applied research on the processing of ferrous and non-ferrous materials, as well as primary and secondary raw materials.

Dr. Guo has coordinated and participated in numerous national and international research projects. His expertise lies in sustainable metallurgy, with a particular focus on high-temperature processing, thermodynamics and thermophysical properties of metallurgical melts, recycling and metal extraction from secondary resources, clean metal production, and the valorization of metallurgical residues. He also has extensive experience in the development of high-temperature experimental facilities and in leading industry-oriented metallurgical research projects.

Dr. Guo has published over 350 scientific papers, with an h-index of 42 and more than 5,700 citations, and has successfully supervised over 30 PhD students.

Henk Bouwer

Executive Technology Development
African Rainbow Minerals

40 years of experience in the ferroalloy industry.

Produced most ferroalloys which include:
Ferrochrome, Medium Carbon Ferrochrome, Ferromanganese, Medium Carbon Ferromanganese, Silicomanganese and Ferrosilicon.

Became the General Manager of a ferroalloy smelter.

Currently the Executive Technology Development at African Rainbow Minerals.

Led the development of the ground-breaking SmeltDirect smelting technology.

In-Ho Jung

Professor
Seoul National University

Professor Jung is a world-renowned expert in chemical metallurgy and thermodynamic database development. He earned his bachelor and master's degree from POSTECH, South Korea and PhD degree from Ecole Polytechnique de Montreal, Canada in 2003, and is a professor in Seoul National University. He is a co-developer of FactSage thermodynamic software, which is accessed by more than 1000 sites around the world, and academic member of FIRE (Federation of International Refractory Research and Education). Since 2009, Prof. Jung has led the "FactSage Steelmaking Consortium Project" to develop thermodynamic databases and process simulation models for steelmaking industry, sponsored by 14 companies around the world. He has authored and co-authored 10 book chapters, and more than 300 journal papers. Prof. Jung received various awards including 2012 NSERC Leo Derikx Synergy Award, Canada, and 2013 Helmholtz-Zentrum Geesthacht Magnesium Research Award, Germany. He is also a recipient of 2022 AIST John F Elliott Lectureship award, and 2025 TMS Sadoway Materials Innovation and Advocacy Award.

Kobus Sutherland

Production Manager
Transalloys (Pty) Ltd

Kobus Sutherland is a highly experienced pyrometallurgical engineer and current Production Manager at Transalloys, with over 30 years of experience in pyrometallurgy including ironmaking and ferroalloy production. He is responsible for the operational and strategic management of five submerged arc furnaces and a converter producing silicomanganese (SiMn), high-carbon ferromanganese (HCFeMn), and medium-carbon ferromanganese (MCFeMn).

His expertise spans furnace operation, process optimisation, reductant and ore strategy, refractory performance, and large-scale production management. Kobus has played an active role in industry collaborative initiatives, including involvement in the HALMAN and PREMA projects, contributing to advancements in manganese alloy process understanding, furnace performance optimisation, and sustainable smelting practices.

Prior to joining Transalloys, he held senior leadership roles at Highveld Steel and Vanadium, where he managed ironmaking operations including multiple furnaces and kilns, and played a key role in the successful implementation of open slag bath smelting technology.

Kobus is an established contributor to the pyrometallurgical community, with multiple peer-reviewed publications and conference presentations focused on furnace tapping systems, tap-hole lifecycle management, and silicomanganese production. His work reflects a strong focus on operational excellence, cost competitiveness, and sustainable metallurgical practices.

Joalet Dalene Steenkamp

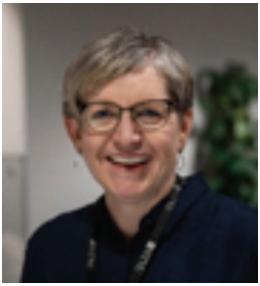
Vale Base Metals

I am passionate about pyrometallurgy with nearly 30 years' experience in metals production. My main technical interests are furnace containment and decarbonization of metals production. I also enjoy empowering others in the field through formal and informal learning experiences. What sets me apart is my unique blend of production background and research expertise. I thrive on the synergy between theory and practice, consistently bridging the gap between fundamental principles and real-world applications. I have a successful track record of facilitating such across commodities, countries, and continents.

Jan Erik Olsen

Research Manager
SINTEF

Jan Erik Olsen has a MSc in physics and PhD in mechanical engineering from the Norwegian University of Science and Technology. He has worked for 23 years in SINTEF which is an independent research foundation. For the last 6 years he has been research manager for the flow technology group. His research focuses on applied CFD with special focus on bubbly flow and metallurgical phenomena. In recent years furnace tapping has been one of the focus areas of his research.



Merete Tangstad

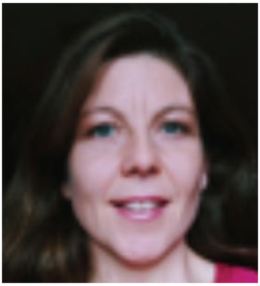
Norwegian University of Science and Technology

Prof. Merete Tangstad took her MSc and PhD at the Norwegian University of Science and Technology and has since 2004 been a professor at the same university. Previously she worked at Elkem and Eramet mainly focusing on Mn-ferroalloy production. Her main areas are silicon- and ferroalloy- production in Submerged Arc Furnaces ranging from raw materials, furnace operation and tapping. She has been co-authoring 7 books and has been the main supervisor of 35 PhD candidates.

Stephan Christiaan Louw

Process Manager
Metix
SMS Group

Stephan is a qualified metallurgical process engineer with 16 years of experience in pyrometallurgical production process management and process design. He started his career in pyrometallurgy at Samancor Chrome, where he gained valuable experience on ferrochrome smelting in DC arc furnaces. He has been employed by Metix, SMS group since 2015, where he has been involved with various projects, spanning over a wide commodity range. With a great passion for the design, modelling, and optimization of metallurgical processes and electric smelting furnaces, he is currently employed as the Process Manager at Metix, focusing on the development of new processes and furnace designs that will assist in making the circular economy and decarbonization of commodities a reality.



Annelies Malfliet

Research expert
KU Leuven

Dr. Annelies Malfliet is a materials engineer specializing in pyrometallurgy, slag engineering, and vessel integrity in high temperature metallurgical processes. She is a member of the Department of Materials Engineering at KU Leuven, where she works within the research group on High Temperature Processes and Industrial Ecology. Her expertise extends to microscopical characterization techniques, supporting detailed analysis of slag–refractory interactions and high temperature material behaviour.

Dr. Malfliet plays a leading role in the development of sustainable metallurgical technologies through KU Leuven's SIM² Institute for Sustainable Metals and Minerals, where she contributes to research on environmentally responsible metal production and recycling, supporting circular economy transitions. Her publication record spans over 100 scientific outputs, ranging from refractory degradation mechanisms in non ferrous smelting to slag engineering, freeze lining formation, and metallurgical ecosystem sustainability.

Across her career, she has collaborated extensively with industry and academic partners, focusing on improving furnace longevity, understanding high temperature phase transformations, and advancing sustainable materials processing. Her research forms a critical bridge between fundamental high temperature thermodynamics and practical industrial metallurgy.

Ferrochrome's future in South Africa: Decline, disruption, or renewal?

S. Swanepoel
Samancor Chrome, South Africa

South Africa's ferrochrome industry, once the crown jewel of global stainless steel supply, now faces an existential crisis. Rising energy costs, infrastructure fragility, and global market realignments have challenged an industry that was built on world-class ore, pioneering technology, and bold industrial vision.

This address reflects on the historical forces that shaped South Africa's ferrochrome sector, from the early days of state-backed smelting development and technology transfer, to the hard-won operational excellence that made local producers world leaders in energy efficiency and technology. Against this backdrop, the presentation explores the structural and policy challenges that threaten competitiveness today, and how the ferrochrome industry's evolution provides lessons for a new era of resilience and reinvention.

The presentation will examine whether ferrochrome has indeed 'lost its shine' or whether a new phase of transformation can strike a new arc to reignite the glow that ferrochrome once had. It calls for pragmatic collaboration between industry, government, and research institutions to rebuild the foundations of competitiveness and ensure that ferrochrome remains central to South Africa's pyrometallurgical future.

South Africa's local beneficiation outlook 2026 and subsequent impacts

N. Bester
Ferroglobe, South Africa

Lack of competitiveness within SA beneficiation due to the wrong energy strategy – what impacted on the dismay of local beneficiation? The energy death spiral and its impact on the footprint of FAPAs members, the heart of local beneficiation. The triple impact factor on beneficiation customers and its consequences. What happened to our local steel and stainless steel capacity? Practical solutions to the critical minerals and metals strategy. Short term wins to recover what was lost over the last decade – hope or despair.

Nellis Bester

Geographic Leader & Chairperson
Ferroglobe South Africa & FAPA

Qualified Metallurgical Engineer, active in the industrial space for more than 30-years and has worked in the Steel industry for more than 10-years and the remainder within the ferroalloys, mining and renewable industries, ranging from Silicon Metal, Ferrosilicon, Foundry products, and Manganese alloys.
Working career both in South Africa and EU within the Ferroalloy industry and Product Management activities. Currently, Geographical Leader of Ferroglobe PLC in SA and the Chairperson for FAPA since several terms.
Passionate about the industry in SA and its resurrection from extinction, to become a leading global beneficiation role player again for SA's local raw materials.

Co-reduction of chromite using hydrogen and silicon carbide

S.P. du Preez, D. Coertzen, Prof. D.G Bessarabov
HySA Infrastructure, South Africa

Ferrochrome (FeCr) is produced from chromite ore by means of carbothermic reduction. During this process (Reaction 1), significant quantities of carbon monoxide (CO) gas are released into the atmosphere.

$FeCr_2O_4 + 4C \rightarrow Fe + 2Cr + 4CO(g)$,   Reaction 1

As alternative to C, a combination of hydrogen (H_2) gas and silicon carbide is considered as reductants, to be employed in a sequential manner. For instance, H_2 is intended to reduce the iron (Fe) oxides at lower temperatures (Reaction 2), while SiC reduced chromium (Cr) oxides at relatively higher temperatures (Reaction 3).

$FeCr_2O_4 + H_2(g) \rightarrow Cr_2O_3 + Fe + H_2O(g)$, Reaction 2

$Cr_2O_3 + SiC \rightarrow 2Cr + SiO_2 + CO(g)$,   Reaction 3

By doing so, 1 mol CO(g) is generated as opposed to 4 mol. Theoretically, C emissions can be reduced by 75%. In this paper, chromite pellets were prepared containing 16 wt% SiC.

Pellets were firstly reduced at 1100°C in H_2, at 1300°C in N_2 (for SiC reduction), or sequentially. During H_2 reduction, Fe metallisation was ~95%. For SiC reduction, Fe and Cr metallisation was ~49 and ~10%, respectively. Sequential reduction yielded Fe and Cr metallisation of 68 and 66%, respectively. It was shown that pre-reduction using H_2 reduced the majority of Fe-oxides, allowing SiC to reduce Cr_2O_3. It was found that Fe metallisation was lower during sequential reduction than during H_2-only reduction. This phenomenon was likely due to Fe reoxidation in the formed acidic slag phase. As SiC reacts with chromite, SiO_2 is ejected to the slag phase, decreasing the basicity index of the slag.

X-ray diffraction analysis showed that during H_2 reduction, metallic Fe and a sesquioxide phase formed. SiC reduction yielded Fe and Cr carbides, and a cordierite phase, i.e., slag. Moreover, metallic Fe formed during H_2 reduction was converted to Fe carbide.

Scanning electron microscopy showed that during SiC reduction, metallic phases, encompassing Fe and Cr, were encapsulated within the slag phase. Various partially reacted chromite particles were also observed, showing an intermediate Fe-stripped phase, containing mainly Cr-, Mg-, and Al-oxides. SEM further showed that the pellets densified, resulting in adverse process gas diffusivity.

From this study, it was proposed that FeCr smelters using closed submerged arc furnaces employ CO-rich off-gas as an energy source, instead of flaring it, to produce SiC from undersized quartz and anthracite on-site. By doing so, the chemical energy associated with the CO-rich off-gas can be stored as SiC, which can be utilised during chromite smelting.

Stephanus Petrus du Preez

Senior Subject Specialist: Hydrogen Energy
HySA Infrastructure (NWU Potchefstroom Campus)

Qualified Metallurgical Engineer, active in the industrial space for more than 30-years and has worked in the Steel industry for more than 10-years and the remainder within the ferroalloys, mining and renewable industries, ranging from Silicon Metal, Ferrosilicon, Foundry products, and Manganese alloys.

Working career both in South Africa and EU within the Ferroalloy industry and Product Management activities. Currently, Geographical Leader of Ferroglobe PLC in SA and the Chairperson for FAPA since several terms.

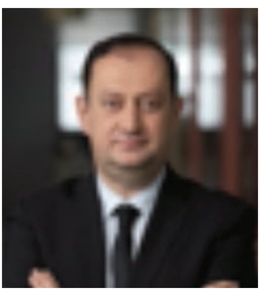
Passionate about the industry in SA and its resurrection from extinction, to become a leading global beneficiation role player again for SA's local raw materials.

The future of coal in a power-hungry world

V. Bayoglu
Menar, South Africa

Unreliable power supply and high electricity costs have gradually eroded South Africa's industrial capacity over the years, crippling the country's ferroalloys and steel sectors. The emergence of power-hungry AI data centres introduces yet another energy-intensive industry competing for a constant and abundant electricity supply. Like smelters, AI data centres require massive amounts of affordable electricity to be available around the clock.

The AI sector is expected to grow exponentially in the coming years, with power grids in leading markets like the US already being strained. In some areas, demand is beginning to exceed electricity capacity. With the data centre boom gaining momentum in South Africa, policymakers need to consider how to maintain a power grid that will fit to withstand growing demand. This requires a realistic assessment of resources that will help the country produce abundant and affordable power. Such a grid for South Africa can only be achieved through coal as the foundation of the country's generational mix.



Mr Vuslat Bayoglu

Managing Director
Menar

Vuslat Bayoglu is the Co-Founder and Managing Director of Menar, a South African mining company with an actively managed and growing portfolio of diversified minerals, which has controlling stakes in Canyon Coal, Kangra, Springlake Colliery, Zululand Anthracite Colliery and East Manganese. The company also jointly owns Khwela Capital, which recently concluded the acquisition of Khwelamet, a manganese alloy smelter complex in Meyerton, Gauteng.

He holds an honours degree in Mechanical Engineering and has over 20 years of experience in the mining industry. Over the years, he has led the group's subsidiaries from junior to mid-tier status through both organic growth and strategic acquisitions.

A hands-on investor, Bayoglu is committed to contributing to South Africa's economic development and is actively engaged in addressing the country's key challenges. He is also a member of DSTI-NRF Cimera Steering committee and he serves on the board of the Richards Bay Coal Terminal (RBCT).

Unlocking a competitive pyrometallurgy industry in South Africa: Challenges, opportunities and the role of Mintek as a national research and technology organisation

E. Matinde[1,2]
[1]Mintek, South Africa
[2]University of the Witwatersrand, South Africa

South Africa hosts some of the world's unparalleled resources for industrial commodities such as chromite, manganese ores, platinum group metals (PGMs), iron ores, vanadiferrous titanomagnetite ores, rare earth metals, coal, among others. These critical minerals are fundamental to global economic growth due to their irreplaceable applications in industrial, transportation, energy generation and storage, communication and manufacturing, among other critical applications. The demand for precursors for industrial and structural alloys (e.g., Cr, Mn, Ti, Fe, Si, Ni, REEs, etc.) and battery and energy metals (e.g., Cu, Ni, Co, Mn, etc.) will naturally increase to satisfy the increased demand for infrastructure, clean energy, agriculture, industrial machinery, among other pressing human needs. Most critical metals and engineering alloys, however, can only be economically extracted and refined at scale via pyrometallurgical approaches. Although most the primary metal production processes have matured and operate optimised flowsheets and technologies, they rely extensively on cheap and abundant carbonaceous reductants, utilise energy-intensive processes to smelt and refine the metals, generate huge amounts of residual hazardous waste streams (such as slags and dusts) and produce toxic and greenhouse gas emissions. These industry-wide challenges therefore present research and technology development opportunities to reduce the environmental footprint of pyrometallurgical processes. The need to increase the ecological footprint and sustainability of pyrometallurgical processes also increases the impetus to develop energy efficient flowsheets with low carbon and effluent emissions, including demonstrating flowsheets incorporating alternative and low-carbon reductants, coupled with the ability to process both primary and secondary feed materials. This paper highlights the role of Mintek as South Africa's national research and technology organisation in providing world-class, integrated RDI infrastructure to facilitate the testing and demonstration of fit-for-purpose flowsheets and technologies.

Elias Matinde

Manager, Pyrometallurgy Division
MINTEK

Elias holds a PhD in Metallurgical Engineering from Tohoku University in Japan, an MBA and a Bachelor of Science degree Metallurgical Engineering from the University of Zimbabwe. Elias has over 20 years of experience in applied research in extractive metallurgy, specialising in the development of sustainable pyrometallurgical processes and technologies. Elias is currently employed as the Manager of the Pyrometallurgy Division at MINTEK. The Division specializes in applied pyrometallurgy research and technology demonstration, with unique capabilities to demonstrate AC/DC EAF smelting processes continuously at scale up to 3MW design capacity, with or without preheating. These capabilities are fully supported by robust thermochemical and computational modelling capabilities using a variety of modelling and simulation software tools.

Power, purpose and possibility: Reframing the future of pyrometallurgy in South Africa

W. Steyn
University of Pretoria, South Africa

The theme 'Foundations of Competitiveness and Sustainability' asks more of us than incremental optimisation. It asks us to reset the foundations of the South African pyrometallurgy industry. The industry stands at a difficult inflection: energy affordability and reliability, tightening global carbon expectations, and fragile supplier ecosystems test even our best plants. Yet, our enduring strengths as a world-class mineral endowment, with deep operational know-how, and a university system capable of cross-disciplinary problem-solving – give us room to move. Speaking from an engineering Dean's vantage point, this address suggests reframing the discussion around the future, focusing on the assets that only we can build together: human capability, digital and data fluency for high-temperature processes, materials innovation that turns liabilities into products, and collaboration that links pyrometallurgy with civil, electrical, data, and environmental engineering. Rather than a list of technical fixes, the presentation proposes near-term and credible pathways to consider, that potentially create momentum, while positioning the sector to compete under new rules in future. The goal is simple and ambitious: to leave the room with rational optimism, practical agency, and a shared commitment to foundations that endure. Skilled people, trusted data, resilient materials ecosystems, and university-industry partnerships that turn constraints into competitiveness and make sustainability a source of strategic advantage for South Africa's pyrometallurgical future.

How will technology advances affect the production of Ferroalloys in the future?

E. Ringdalen
SINTEF, Norway

Products from the Ferroalloy industry are crucial for our daily life and their importance is increasing. The industry is facing several challenges that need to be solved. Technological advances are, as is the tradition in this industry, expected to be a main contributor to overcome these. Important challenges are to ensure sustainable production with net zero CO2 emission; low environmental footprint, economic feasibility with increasing energy scarcity and cost, and also to meet the expected changes in raw material quality and availability and political aims to be self-sufficient with critical raw materials within own regions as, for instance, Europe. This is expected to trigger developments of completely new processes and technologies; new technologies for preprocessing and postprocessing and developments in furnace technologies as well as competence to improve existing production processes.

Developments are often necessarily alloy-specific and related to the conditions for producing a specific alloy or related to high temperature processes at reducing conditions – which is the case for most of metal production. At the same time there is rapid technological development within other metal producers and sectors from which the ferroalloy industry can benefit. Ferroalloy furnaces are to some extent like a 'black box' with limited possibility to measure conditions inside. Expected advances within sensor technologies have thus the potential to improve existing processes and increase feasibility of new processes. A prerequisite to benefit from this is that new data from the sensors are coupled to and used to increase process competence. This can be followed by better simulations of the process and use of AI tools.

Changes in raw material qualities is an example of challenges that are expected to generate and benefit from technological advances. Raw material with lower content of valuable element must be upgraded before use, resulting in raw materials with finer particle size. Technologies where furnaces or reactors can be fed with fines instead of lump materials and technologies for production of agglomerates will thus probably be developed within several branches. Use of composite agglomerates and adaption of furnace design and process operation is a natural part of this.

Technological advances are expected both within raw materials, furnace technologies, sensors and others. Examples of different combinations of challenges and possible technological advances, and how they can contribute to developments in the ferroalloy industry will be presented and discussed.

Influence of oxidative sintering on the hydrogen reduction of industrially-produced pellets

D. Coertzen, D.G. Bessarobov, S.P. du Preez
HySA Infrastructure, South Africa

Chromite is an important mineral that is used in the production of ferrochrome (FeCr). FeCr, in turn, is mainly consumed by the stainless-steel industry. The production of FeCr is a highly carbothermic and energy-intensive process. Carbon (C) is used as a reductant, which results in large amounts of C emissions. To lower the C emissions of this process, hydrogen is proposed as a pre-reductant (Reactions 1 for C and 2 for hydrogen). Using hydrogen, $H_2O(g)$ is produced as a by-product along with Cr_2O_3, which is then reduced during smelting to chromium (Cr) metal. The reduction of chromite using C and hydrogen is as follows:

$FeCr_2O_4 + 4C \rightarrow Fe + 2Cr + 4CO(g)$, $\Delta H° = 1015.96$ kJ Reaction 1

$FeCr_2O_4 + H_2(g) \rightarrow Cr_2O_3 + Fe + H^2O(g)$, $\Delta H° = 81.60$ kJ Reaction 2

The majority of SA chromite requires agglomeration, for which the Outotec process is mainly used. It has been shown that oxidatively sintered pellets require ~200 kWh/ton FeCr less energy to be smelted when compared to raw ore. This is due to the liberation of Fe from the chromite spinel, yielding Fe^{3+} as a semi-segregated phase. This segregated phase, though occurring in a higher oxidation state, is more susceptible to reduction than its spinel-bound counterpart.

This paper investigated the use of hydrogen as a pre-reductant for oxidatively sintered chromite pellets obtained from industry. Pellets from four Sinter Plants (SP 1 – 4) were used, all employing the Outotec process. Pellets were reduced using hydrogen at 1100°C for up to 120 min, achieving Fe metallisation of 48.1 – 69.2%, while Cr metallisation remained limited.

XRD indicated the presence of a sesquioxide phase in varying degrees for each of the SPs. The sesquioxide phase is present in a so-called Widmanstätten pattern, which was used to semi-quantitatively determine the presence and extent of oxidation. It was found that the various SPs have very dissimilar degrees of oxidation, suggesting that SPs employing similar technology yielded pellets with dissimilar degrees of oxidation.

SEM indicated that SP 3 and 1 had the highest degree of oxidation, seen as the Widmanstätten pattern occurring throughout the pellets, correlating with higher metallisation (69.3 and 63.7% respectively). The opposite was true for SP 4 pellets (Fe metallisation of 48.1%), whereas the SP 2 pellets showed an intermediate degree of oxidation and metallisation (61.4%).

As the Outotec process is used to create mechanically-strong pellets, pellet break-strength testing showed that hydrogen reduction adversely affected pellet mechanical integrity. However, the obtained break strength was still sufficient for smelting. A preliminary cost analysis showed a reduced cost increase from 75.65 ZAR (smelting using anthracite) to 262.83 ZAR (pre-reduction with hydrogen followed by smelting with anthracite) to process 1 kmol (224 kg) of chromite. Such a decrease corresponds to an estimated reduction of 566,280 – 809 640 t CO_2/annum and carbon tax savings of 67.9 – 97.2 million ZAR.

De Wet Coertzen

Ph.D. Student
HySA Infrastructure (NWU Potchefstroom Campus)

De Wet Coertzen is a Ph.D. candidate in chemical engineering at HySA Infrastructure at the North-West University's Potchefstroom campus, with a focus on greener FeCr production. He obtained his B.Sc. in chemistry and physiology from the NWU in 2015, completing his B.Sc. Hons in Chemistry and M.Sc. in Chemistry in 2016 and 2019, respectively. His master's degree focused on electrolyser catalysts for the oxygen evolution reaction (OER) in alkaline media, publishing two papers on the topic of carbon supports and $Ir_xNi_yO_z$ catalysts for the OER in alkaline media. In 2021, he completed an Occupational Hygiene Training Association (OHTA) course. He received a W201 certificate in Basic Principles of Occupational Hygiene from the South African Institute for Occupational Hygiene (SAIOH) under the OHTA qualifications framework. He has a passion for research and aims to provide more insight into a greener approach to metallurgy and mining.

Industrial validation and process modelling of biocarbon-chromite briquettes for fossil CO_2 mitigation in FeCr production

E. Mousa[1], K. Manu[1], A. Tomy[1], D. Attah-Kyei[1], A. Papadopoulos[2], L. Ånnhagen[2], G. Hauri[2], G. Gubasheva Aktan[2], N. Tiraani[2]
[1]Swerim, Sweden
[2]Vargön Alloys AB, Sweden

Ferrochromium (FeCr) alloy production, a critical input for stainless and specialty steels, is characterised by a high fossil carbon footprint stemming from its reliance on coke in the submerged arc furnace (SAF). This paper investigates a direct and sustainable pathway to decarbonisation through the industrial application and quantified performance of biocarbon-chromite ore briquettes. On a technical scale, briquettes were developed using vibro-press (up to 10% biocarbon) and roller-press (up to 20% biocarbon) techniques. To maximise resource efficiency and circularity between the specialty steel and FeCr sectors, mill scale was integrated into the briquettes as an iron carrier. The material development phase, focused on achieving adequate cold and hot mechanical strength, was systematically followed by successful pre-industrial trials. The resulting biocarbon-mill scale-chromite briquettes were then subjected to a full industrial campaign and charged into a commercial SAF at Vargön Alloys. The campaign, which was accompanied by online dust collection and gas measurement, confirmed the briquettes' structural integrity and demonstrated acceptable operational performance under the industrial conditions, validating their viability for partial replacement of fossil coke in the FeCr production. To provide quantitative evidence of the process shift, a detailed heat and mass balance analysis was executed using the HSC thermochemical software model. The combined industrial operational data and thermodynamic modeling results definitively confirm an improved overall process efficiency within the SAF. Crucially, the analysis precisely determined the significant mitigation of fossil CO_2 emissions achieved by partial substituting coke with biocarbon, providing a direct, measurable environmental benefit for the ferroalloys sector. This research validates an innovative, industrially mature, and measurable pathway toward the decarbonisation of the FeCr industry. This work is part of the FEMOST project (2023-02489), conducted in collaboration with Swerim, Vargön Alloys, Future Eco, Ovako, Uddeholms, and RISE, and financed by the Vinnova funding agency in Sweden.

Review of phase relations in the $FeO-Cr_2O_3-Al_2O_3-MgO-CaO-SiO_2$ system in the compositional range applicable to ferrochrome slags

T.G. Ntloko[1,2], X.C. Goso[1], E. Matinde[1,2], P. Den Hoed[2]
[1]Mintek, South Africa
[2]University of Witwatersrand, South Africa

This paper reviews the phase relations in the $FeO-Cr_2O_3-Al_2O_3-MgO-CaO-SiO_2$ system in the compositional range applicable to ferrochrome slags, with a view to finding conditions for maximising the deportment of Cr to a chrome-spinel, and crystallising, stabilising, and growing this chrome-spinel for subsequent extraction by a physical beneficiation process. Chrome-spinel would serve as a valuable concentrate for extracting Cr.

The testwork was conducted using a combination of thermochemical simulations by FactSage 8.3 and classical equilibration-quench experiments coupled with electron probe microanalysis (EPMA). The reviewed FeCr slags comprised of 29.43% Al_2O_3, 33.32% SiO_2, 11.53%–23.06% MgO, 0.00%–11.53% CaO, 2.25%–7.09% FeO_x, and 7.09%–11.08% CrO_x.

Phase equilibrium diagrams showed that the crystallisation of phases in the reviewed synthetic FeCr slags occurred over a large temperature range of 1280°C to 2180°C, with the chromium-bearing spinel crystallising as the primary phase, while cordierite, pyroxenes, anorthite, and olivine crystallised as secondary, tertiary, and quaternary phases, respectively. Experimental results showed that the deportment of chromium species to the spinel phase increased with decreasing temperature or cooling up to a temperature of approximately 1400 °C. The results also showed that the residual slag phase had minor concentrations of chromium and metallic species, rendering the slag suitable for recycling/usage in various industries.

Choosing to compete: South Africa's pyrometallurgy sector in a shifting world

C. Hattingh
Centre For Risk Analysis, South Africa

South Africa's pyrometallurgy sector sits at an inflection point; endowed with an unrivalled mineral resource base yet constrained by energy costs, logistics bottlenecks, and a decade of industrial attrition. This presentation argues that the path forward is not primarily a function of policy relief or commodity cycles, but of deliberate choice: how industry, researchers, and government choose to engage with each other, with the economy, and with emerging opportunity. Drawing on sector data and observations from international engagements across the United States and beyond, it makes the case for measured optimism - noting that while Europe and China face a difficult decade of demographic and energy constraints, the global environment is, for the first time in years, shifting in South Africa's favour. The question before this industry is not whether it can compete, but whether it will choose to.

Opportunities for the South African iron and steel industry in a changing world

V. Karplus, C. Pistorius
Carnegie Mellon University, USA

While a number of technology pathways to support deep decarbonisation of the iron and steel industry have been proposed, it is often unclear under what conditions regions and plants should adopt them. In our presentation, we will combine insights from an open-source tool, the decarbSTEEL (the Decarbonising Steelmaking TechnoEconomic EvaLuation) Tool Version 5, and a machine-learning-based model of the global iron and steel industry to consider opportunities for the industry in South Africa. Interpretation of our analysis will be informed by observations from an 8-day study tour of the iron and steel industry in South Africa and Namibia during May 10-18, 2026. Our remarks are intended as a starting point for further customising analysis to help answer major questions the industry is currently facing.

Valerie Karplus

Carnegie Mellon University

Valerie Karplus is a professor in the Department of Engineering and Public Policy and associate director at the Wilton E. Scott Institute for Energy Innovation. Karplus studies resource and environmental management in organizations operating in diverse national and industry contexts, with a focus on the role of institutions and management practices in explaining performance. Areas of expertise include innovation in iron and steelmaking, regional approaches to workforce and economic revitalization, and the integrated design and evaluation of public policies. At CMU, she runs the Laboratory for Energy and Organizations.

Chris Pistorius

Carnegie Mellon University

P. Chris Pistorius is a metallurgical engineer whose research focuses on production of metals and alloys, mainly steel, and corrosion. A native South African, he received bachelor's and master's degrees in metallurgical engineering from the University of Pretoria, and completed a Ph.D. in corrosion at the University of Cambridge. He was an associate professor and then professor in the Department of Materials Science and Metallurgical Engineering, University of Pretoria, South Africa, from 1991 to 2008. He served as head of that department from May 2002 to June 2008.

A method of determining and optimising the capacity of individual equipment for improved utilisation of the asset

D.B. Grant
DC Connections and Engineers, South Africa

Sustainable competitiveness in pyrometallurgical operations increasingly depends on maximising the effective capacity of existing assets rather than large-scale capital expansion. This presentation examines how the true productive capacity of smelting and refining plants evolves from the initial design intent to the 'as-built' and 'as-aged' states, highlighting how capacity creep and operational pressures drive plants to operate beyond nameplate limits.

A structured framework and utilisation modelling tool have been developed to quantify plant capacity at equipment and component levels. The approach combines operational data analysis with reliability and control-system assessments to distinguish real from perceived constraints. Case studies demonstrate how the method identifies bottlenecks, supports decision-making on maintenance intervals, control-loop upgrades, and equipment retrofits, and quantifies the effect of such interventions on overall plant utilisation.

This presentation offers a pragmatic method for engineers and managers to achieve higher utilisation and sustainability in modern pyrometallurgical plants.

Donald Bruce Grant

Director
DC Connections and Engineers

Donald Grant is an Engineer with over 30 years' experience in the smelting industry. He has applied experience across a range of large plant operation including logistics, operations management, maintenance management, new furnace builds and rebuilds.

Donald worked within the Samancor Chrome group for over 34 years, at the Middelburg Ferrochrome operation and subsequently in the role of Group Projects Manager since 2022. He was on the team that built the M3 DC Arc Furnace in 1997 and subsequently M4 DC Arc furnace in 2007 and has been close to the continuous development of the assets.

Donald was involved in organisation wide projects and maintenance management activities for over 20 years and has specialised in plant design and continuous improvement.

KPI Trees as guide and reference tool for improvement

H. Kotzé
Tronox, South Africa

Escalating costs and demanding market conditions compel high performance levels from limited resources. Under these conditions we are often handed blind goals without tangible roadmaps on how to achieve these, while working to gain as much benefit as possible from our efforts. This paper argues that key performance indicator (KPI) trees are central in navigating these conditions. KPI shines in highlighting opportunities and pitfalls when challenged with multiple efforts and untangling the how-to of a blind goal. A well-constructed KPI tree highlights the drivers, their impacts on the outcome, inter-dependence between drivers, and improvement opportunities each driver holds. It sets the basis for cost-benefit analyses and has a central role in cross-checking the benefits from several projects: checking unrealistic commitments in the planning phase and measuring success in the implementation phase. By understanding the basis for KPI targets, the KPI tree can also be used to challenge perceived targets. This paper demonstrates these concepts with three examples: how a KPI tree can be used to keep commitments honest, untangle blind goals into tangible targets, and break through perceived limitations.

Hanlie Kotzé
Tronox Mineral Sands
Senior Principal Engineer – Business Improvement

Hanlie studied metallurgical engineering at the University of Pretoria after which she commenced working at what today is known as Tronox Mineral Sands. She was lead commissioning engineer on the first start-up of the KZN ilmenite smelters. Over time Hanlie worked in various roles including Manager Technical Services until she resigned at the end of 2007. During the following years she consulted to various DC and AC smelters other than ilmenite. In 2021 Hanlie re-joined Tronox as Senior Principal Engineer, and today is Lead of the Smelting Centre of Excellence. She works with pyrometallurgist at the Tronox Namakwa and KZN Sands sites aiming to improve smelting operations and deepen the collective knowledge of ilmenite smelting.

Digital solutions for competitive and sustainable pyrometallurgy – towards Industry 5

J.H. Zietsman
Ex Mente Technologies, South Africa

The pyrometallurgical industry is under pressure to boost efficiency, sustainability, and competitiveness in a rapidly changing global landscape. This presentation explores how advanced digital solutions address these challenges, using a chromite sintering simulator and DRI smelting furnace process models as key examples. We demonstrate a progression from training tools to operational support systems, soft sensors, and closed-loop control, driving operational excellence and environmental stewardship.

Through case studies in chromite sintering and smelting, PGM smelting, and green ironmaking, we showcase practical impacts – enhanced process understanding, accelerated technology development, optimised performance, and reduced environmental footprints. These applications leverage digital frameworks for material descriptions, material behaviour analysis, and process modelling; supporting the technology lifecycle from conceptualisation to sustainable and profitable operation.

Looking ahead, we envision integrating these modelling infrastructures with model context protocol APIs, enabling seamless data access for humans, systems, and artificial intelligence tools like large language models. This fosters innovation, empowers engineers through training, and enhances knowledge-capture and utilisation, aligning with Industry 5.0's human-centric, AI-enabled, technology-driven, and knowledge-rich future. By bridging current capabilities with forward-looking possibilities, this talk underscores how digital solutions build foundations for a competitive, sustainable pyrometallurgical industry, supporting the conference theme of long-term success.

Advances in pyrometallurgical piloting

N. Sweeten, S. Ritchie, M. Sidawi, K. Marais, S. Maharaj, K. Chomyn
Hatch (Pty) Ltd., South Africa

The global metallurgical industry faces many challenges, providing opportunities for engineering innovation with exciting new projects, whether it involves extracting critical minerals, promoting circularity, shifting to green metals production or simply improving efficiency to increase profitability. During the development and commercialisation of new processes and technologies, it is essential to assess the readiness and maturity of each application and mitigate any significant risks before implementation at commercial scale. Pilot testing can often be an effective tool for de-risking new technologies and ensuring successful project outcomes, when well-executed. A key outcome of piloting should be metallurgical understanding; however, it is also important that the pilot programme is designed to provide information required to enable the scale-up and design of practical, reliable, and high-performing equipment.

This test work campaign was a portion of a maturation plan for a pyrometallurgical technology. The paper covers from problem definition to the design of the pilot furnace and monitoring systems, through to test execution and data analysis. The test work setup employed advanced monitoring techniques, including real-time off-gas analysis and high-temperature bath video, to gain novel insights into process behaviour. The paper also demonstrates how a computational model, developed in parallel with the test work and validated against experimental results, is a powerful tool to support process and equipment scale-up.

Nicole Jane Sweeten

Process Engineer
Hatch Africa Pty Ltd

After finishing her chemical engineering degree at the University of Pretoria, Nicole fell in love with pyrometallurgy during her first job at Resonant Environmental Technologies. She then returned to UP to deepen her knowledge by completing a Master's in Metallurgical Engineering, her project involving the CFD modelling of a PGM furnace. She then spent 6 years at Ex Mente using thermochemistry to study novel pyrometallurgical processes in the ferroalloy and PGM industries, taking some of these new concepts through to piloting. Since joining Hatch in 2022 she has focused largely on Green Steel technology development, managing a global team to execute a portfolio of modelling, design, and piloting work to support innovation in iron and steel production.

Coupling thermochemistry and multiphysics models for simulation of pyrometallurgical processes

A. Bogaers, M. Rajh, W. Roos, J. Zietsman
Ex Mente Technologies, South Africa

Incorporating thermochemical equilibrium calculations into process and multiphysics models can provide significant insights into industry-relevant processes that current modelling or measurements cannot. By including phase stability as well as composition- and temperature-dependent material properties, these models can more accurately describe phenomena observed in pyrometallurgy such as melting, smelting, solidification, chemical reactions, dissolution, and gas evolution.

In this work, we present an integrated modelling framework developed for OpenFOAM that couples detailed thermochemical equilibrium calculations with multi-phase flow, heat transfer, and mass transport. The framework is demonstrated using a selection of relevant verification cases. These cases aim to highlight the framework's ability to handle complex phase transitions, species transport driven by convection and both thermal and solutal buoyancy, and the resulting macrosegregation. Furthermore, they showcase the dynamic evolution of composition- and temperature-dependent material properties during the solidification of an alloy.

Beyond these examples, this approach will enable coupling thermochemical equilibrium calculations with process and multiphysics models, which will provide new insights into process and furnace behaviour. It also establishes a foundation for developing digital twins and soft-sensor frameworks, linking fundamental thermodynamics with plant-scale data for improved process understanding and operational decision-making.

Alfred Edward Jules Bogaers

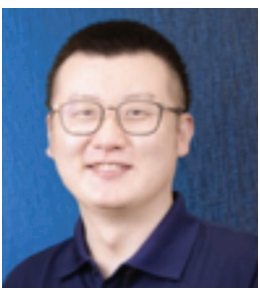
Principal Engineer
Ex Mente Technologies

Alfred is a Principal Engineer within the Multiphysics Modelling group at Ex Mente Technologies. He has spent the majority of his career developing new solvers and numerical techniques to tackle complex multiphysics problems, including fluid-structure interactions, conjugate heat transfer, and electromagnetics. He holds a PhD in Applied Mathematics from the University of Cape Town and Master of Engineering from the University of Pretoria.

Beyond the numbers: Material property insights as the hidden foundation of furnace performance

M. Zhu[1], S. Koning[1], H. Muire[1], W.A. Roos[1], J.H. Zietsman[1,2]
[1]Ex Mente Technologies, South Africa
[2]University of Pretoria, South Africa

South African pyrometallurgical producers, including those in chromium, manganese, and platinum group metal (PGM) production, are facing increasing pressure from rising electricity costs, electricity-supply constraints, shortened furnace campaign lives, and tightening economic and environmental regulations. To remain economically viable under these external constraints, the industry is compelled to move beyond conservative, experience-based design margins toward more precise furnace operation supported by physically credible modelling. However, the value of digital modelling tools is frequently limited by uncertainty in input parameters, specifically, material properties. As the hidden foundation of reactor performance, properties such as slag viscosity and thermal conductivity govern critical heat and mass transport phenomena. Their values often carry significant uncertainty, which propagates through simulations and contributes to uncertainty in furnace behaviour, performance, and profitability. This paper examines how uncertainty in high-temperature material property descriptions influences pyrometallurgical furnace modelling. Material properties are first linked to process behaviour through transport arguments and dimensionless-number analysis. A representative multiphysics furnace case, based on direct reduced iron smelting, is then used to illustrate how uncertainty in selected inputs can affect heat-transfer interpretation, furnace sizing, and throughput estimates. The paper further discusses two complementary approaches for improving material property descriptions: physically constrained bounds for slag thermal conductivity, informed by slag structure and heat-transport considerations, and auxi-mpp, an open-source Python library that supports more consistent implementation of slag, alloy, and gas property models in process and multiphysics workflows. Together, these examples illustrate how physically grounded material property descriptions can reduce ambiguity in model inputs and support more consistent engineering interpretation.



Mengyi Zhu

Computational scientist
Ex Mente Technologies

Dr. Mengyi Zhu received his bachelor's degree in metallurgical engineering from the University of Science and Technology Beijing, his master's from RWTH Aachen University in Germany, and his Ph.D. from the Norwegian University of Science and Technology (NTNU) in 2021 in Norway, after which he continued his postdoctoral research at NTNU. In 2025, he joined Ex Mente Technologies as a computational scientist. His research interests encompass slag science and engineering, focusing on the atomistic structural origins of fundamental slag properties in multicomponent systems and their integration into physically informed modelling frameworks for high-temperature process simulation.

Technology evolution in the Southern African Ni-Cu-PGM smelting industry

R. Hundermark, G. Marsden, R. Snodgrass, K. van der Merwe
Valterra Platinum, South Africa

The Southern African Ni-Cu-PGM smelting industry has evolved significantly from 1937 to date. As demand for platinum group metals (PGMs) has increased, smelting technology development has been closely linked to the need to process more concentrate, but also to changes in the chemistry and mineralogy of concentrates from the various PGM-containing reef types.

Early technologies relied on blast furnaces and Great Falls converters, but from the late 1960s, electric furnaces and Peirce Smith converters were commissioned. In the early 1990s, the introduction of water-cooled copper plate coolers into the slag zones of the primary furnaces enabled greater power intensity and throughput, with further intensification from the early 2000s requiring the use of deep-cooled copper coolers. Converting technology was also modernised to include a top submerged lance converter in one instance. Approaches to converter slag cleaning have evolved from recycling slag to the primary furnaces, to milling and flotation or electric furnace slag cleaning as the Cr_2O_3 content in slags has increased.

The shift in the 1990s from Merensky ore-derived concentrates to those from UG2 ores impacted the process design for the primary furnaces, with UG2 concentrates having lower matte falls and higher Cr_2O_3 levels. Conversely, concentrates derived from Platreef and Great Dyke ores, with high matte falls and lower Cr_2O_3 levels, have introduced other challenges. Furnace designs and operating philosophies have been improved to better handle these ranges of concentrates, the resulting slags and superheated mattes, the containment of which is non-trivial. The smelting of non-roasted concentrates in the primary furnaces gave rise to rapid corrosion of the copper coolers, and triggered development of corrosion mitigation strategies.

Advances in SO_2 emissions control have transitioned from single contact sulfuric acid plants in the 1970s, to the adoption of double contact acid plants, tailgas and dual-alkali scrubbing in the early 2000s. Low SO_2 strength offgas streams from primary furnaces are abated in some cases, with technologies such as the Sulfacid process introduced from the early 2000s and the Wet-gas Sulfuric Acid process from the early 2020s.

With advances in process intensification, increases in operating temperatures and throughputs, and use of water cooling, consequences of furnace failures have become more severe. Water leaks into the molten material environment, primary furnace containment and slag granulation have been particularly challenging. Technologies, operating and maintenance philosophies have been developed for prevention and mitigation of failures, and the adoption of Process Safety Management approaches has yielded systematic benefits.

With the outlook in demand for PGMs changing as a function of automotive requirements, smelting technology will continue to evolve for further enhancement of safety and environmental protection, reduced costs and greater efficiencies.

The full paper will be published in the SAIMM Journal

Operational strategies for capacity increase and steady-state operation at the Northam Platinum Zondereinde

J.L.M. van der Merwe
Northam Platinum Holdings, South Africa

This paper describes the operational strategies that enabled Northam Platinum's Zondereinde smelter to grow from a single 10 MW furnace operation running five days a week to a two-furnace operation producing in excess of one million ounces of platinum group metals (PGMs) per annum. This transformation was achieved during a period of pricing and exchange rate volatility, loadshedding, and significant changes in concentrate mineralogy as the Bushveld Complex shifted from Merensky to UG2-dominant mining. Rather than relying on a single transformative intervention, the capacity increase was realised through the sustained application of incremental operational improvements across four areas: targeted workforce development focused on control room operators, the use of mobile messaging technology for real-time operational discipline, systematic concentrate blending to manage changing feed characteristics, and the decoupling of slag handling from furnace operations. Matte fall was stabilised at approximately 5%, compared with 10% or more at comparable operations. The paper discusses the practical lessons learned during this process, including the importance of investing in information quality, the value of testing blending theories through controlled furnace trials, and the role of infrastructure improvements in sustaining operational gains. The experience demonstrates that consistent, focused operational discipline — applied daily over an extended period — can deliver step-change improvements in smelter performance.

Martin van der Merwe

Departmental Manager : Smelter, PMRF and Slag Plant
Northam Platinum Limited

Martin van der Merwe has more than 36 years experience in primarily the PGM industry, in positions of engineering management and process management. He is presently the Departmental Manager for the Smelter, Precious Metals Recycling Facility and Slag Plant at the Northam Platinum Zondereinde Processing Plant.

Martin's career history demonstrates his successful integration of electrical engineering expertise with metallurgical process knowledge, culminating in industry-best operation of furnaces in terms of crucible longevity, operational control and electrical efficiency, particularly with problematic high-chrome, low matte-fall feed sources.

Martin's exceptional approach to operational discipline has stood him in good stead during his career, principles that he will share with the audience during his presentation.

Microstructural evaluation of magnesia-chromite bricks exposed to PGMs matte zone conditions

A. Nyembwe
University of the Witwatersrand, South Africa

The integrity of the furnace crucible or hearth is critical in pyrometallurgical operations where hot liquid slag and matte are produced. In platinum group metals (PGMs) smelters with high-temperature operations, furnace crucibles are lined with refractory materials such as graphite blocks and magnesia-chromite bricks coupled with an integrated cooling system. This cooling system, installed on the cold face of the refractory lining, extracts sufficient thermal energy to promote the formation of a freeze lining within the slag zone. While graphite and magnesia-chromite refractories have demonstrated resistance to slag corrosion, the interaction between magnesia-chromite bricks and high-superheat PGMs matte has not been fully investigated. In this paper, samples of spent refractory bricks were retrieved from the skew brick zone during a partial shutdown and analysed using scanning electron microscopy–energy dispersive spectroscopy. The analysis revealed extensive degradation of the primary phases—chromite and periclase—across the examined samples. Microstructural analysis along the centreline and two parallel sections of the bricks highlighted significant chemical interactions between the matte and refractory material. The magnesia-chromite components reacted with the matte to form compounds such as chromium sulfide (CrS) and ferrous oxide (FeO), both of which are soluble in matte. These findings confirm that the operational temperature of the matte exceeded 1500°C.

Alain Nyembwe

University of the Witwatersrand

Alain Nyembwe holds a doctorate degree in Materials Science and Metallurgical Engineering from the University of Pretoria. I was involved in research at the Centre of Pyrometallurgy at the University of Pretoria for over 10 years. I obtained all my postgraduate degrees, honours, Master's and doctorate (PhD) at the University of Pretoria. My research fields involve the computational/mathematical modelling of fine iron ore granulation and the investigation of refractory bricks and freeze lining in PGM smelters. I have joined Wits as a Lecturer of Pyrometallurgy-based courses since 2022. Some of my recent projects involve the decarburising of HC-FeCr for the Foundry industry, Gold-tailings incorporation in the cement production and modelling of matte entrainment in the slag during slag tapping, aluminium can (UBC) recycling and H_2-CO reduction of chromite and hematite. In addition, my research includes the development of new materials such as high-entropy alloys, biosensors, and adsorbents for water purification.

Process optimisation of a PCB smelting process via improved slag design

C. Sagadin, A. Filzwieser
Mettop GmbH, Austria

The pyrometallurgical processing of PCB-based electronic waste represents a key route for recovering copper and precious metals from PCB scrap. In this paper, a comprehensive optimisation programme was carried out on an existing PCB smelter by combining thermodynamic process simulation, targeted slag engineering and industrial scale validation. A technical evaluation indicated that the existing process reduces metal recovery and limited the potential for downstream refining technologies.

Thermodynamic calculations were used to redesign the slag composition and to define improved operating windows for smelting. The thermodynamic calculations were applied on-site at the smelter, where the revised slag operating regime was implemented and validated. These on-site trials demonstrated that an adjusted slag practice can significantly improve metal recovery and overall process stability. The new slag formulation exhibited a lower viscosity and a more favourable phase composition, which led to significantly improved slag–metal separation, reduced energy demand and more stable furnace performance. Following this optimisation, the process chain will be expanded by installing the Mettop Mini Smelter technology to convert the produced black copper into raw copper. This step enabled the generation of a stable and consistent copper quality suitable for electrolytic refining. In addition, an electrolytic refinery and a precious metals plant are being implemented, allowing the on-site production of high purity gold, silver and platinum group metals.

Esli Bantjes

Project Manager
METTOP GmbH

With a strong technical background and extensive hands-on industry experience, he has built a career dedicated to supporting and advancing the pyrometallurgical industry. After completing his studies in the field of electromechanics, he developed a deep understanding of electrical principles and industrial systems, which became the foundation for his professional path in high-temperature metallurgical applications.

Early in his career, he focused on the manufacturing and development of pyrometallurgical cooling components for the global smelting industry. Through years of practical involvement in complex industrial environments, he gained comprehensive expertise in cooling technologies, furnace operations, and the demanding requirements of modern metallurgical processes. His technical understanding, combined with a solution-oriented mindset, enabled him to contribute to reliable and efficient cooling solutions that support operational safety, process stability, and long-term equipment performance.

Over the course of his professional journey, he has accumulated more than 15 years of experience in the pyrometallurgical sector. During this time, he has worked closely with customers, engineering teams, and production specialists across a wide range of international projects. His experience spans from technical consulting and project coordination to customer support and the successful implementation of tailor-made cooling solutions for challenging industrial applications.

In May 2023, he joined the METTOP team, where he continues to contribute his expertise and industry knowledge in the role of Sales Manager and Project Manager for cooling elements. In this position, he combines technical know-how with strong project management and customer relationship skills, supporting clients from the initial project phase through to implementation and after-sales service.
His practical industry experience allows him to understand customer challenges in depth and to develop reliable, efficient, and sustainable solutions tailored to specific operational requirements.

As part of the METTOP team, he is actively involved in strengthening the company's position as a trusted partner for innovative pyrometallurgical technologies and cooling solutions. His dedication to quality, technical excellence, and customer satisfaction reflects the values that drive METTOP's approach to industrial innovation and long-term partnership.

With his combination of technical expertise, industry experience, and commitment to practical solutions, he brings valuable insight into the challenges and future developments of the pyrometallurgical industry. His contribution supports not only the successful realization of projects, but also the continuous advancement of technologies that improve operational performance, safety, and sustainability within the global smelting sector.

Mechanical conveying and crushing of waste heat boiler dust

E. Lehtilä, H. Talvensaari
Kopar Oy, Finland

This paper addresses the optimisation of drag chain conveyors utilised in Waste Heat Boiler (WHB) systems, focusing on enhancing operational reliability under high-temperature conditions. The research combines material science, thermal analysis, and mechanical design principles to mitigate wear and failure risks in demanding metallurgical environments.

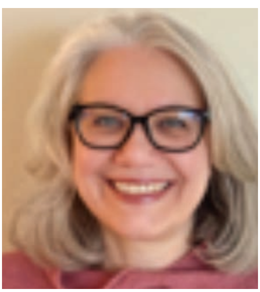
The paper examines the influence of Waste Heat Boiler (WHB) design parameters on thermal profiles and particulate flow dynamics within the drag chain conveyor, the connection between the WHB and conveyor system, and the optimisation of material selection for conveyor components under high-temperature and abrasive conditions. Computational Fluid Dynamics (CFD) simulations complement these findings by modelling heat distribution and airflow patterns within the WHB, enabling accurate prediction of thermal stresses on conveyor components.

The findings highlight the importance of optimised grate structures to ensure uniform load distribution, integrating expansion allowances to counteract thermal elongation, and adopting advanced surface treatments to minimise abrasive wear. Furthermore, the study emphasises the importance of predictive maintenance supported by real-time monitoring of temperature and mechanical loads.
The proposed optimisation framework demonstrates significant potential for extending equipment lifespan, reducing unplanned downtime, and improving overall energy efficiency in smelting operations. By aligning empirical data with simulation-driven insights, this paper provides a comprehensive approach to conveyor design under extreme thermal conditions, contributing to sustainable and cost-effective plant performance.

Production of critical metals from waste streams

G. Tranell
Norwegian University of Science and Technology, Norway

Both production of metals and waste end-of-life management typically comes with environmental burdens such as slags, sludges/dust and fugitive emissions. An increased focus on resource efficiency and lowering the specific carbon footprint for common and critical metals has led to new and innovative technologies for recovery and production of metals. In this paper the focus will be on experiences and results from both EU projects and Norwegian programmes. Examples such silicon and manganese production from slags and drosses, extraction of manganese from off-gas wet scrubbing sludges, as well as recovery of Cu and Zn from municipal waste incineration ashes will be described.



Gabriella Tranell

Scientific Director
Norwegian Centre for Zero Emission Metal Production (FME ZeMe)

Professor Gabriella Tranell holds a MSc in Geotechnology/Metallurgy from LTU, Sweden and a PhD in Materials Science and Engineering from UNSW, Australia. Prior to joining NTNU as professor in 2009, she worked as Senior Scientist and Research Manager with SINTEF. She has initiated and led several large EU projects and national research centres for extractive metallurgy. She is currently scientific director of the Norwegian Centre for Zero Emission Metal Production (FME ZeMe).

Her current research interests and activities include:
- Production, refining and recycling of Ferroalloys and Silicon
- Refining and recycling of aluminium
- Solar cell materials
- Environmental issues and emission related to metal production
- Valorization of metallurgical sidestreams and MSWI ashes.

Recovery of zinc and germanium from copper slag via reduction roasting

K. Zitha
University of Johannesburg South Africa

The recovery of zinc and germanium from copper slag has not been extensively studied.
This paper investigated the recovery of these elements from copper slag using the reduction roasting method.

Coke was employed as the reductant to extract germanium and zinc from copper slag obtained from the Gécamines copper smelter plant in Lubumbashi, Katanga Province, Democratic Republic of Congo.

The experimental results showed that 6.4% recovery of germanium was achieved, whereas zinc recovery was limited to only 0.04%.
In the slag, germanium was present as germanium dioxide (GeO_2) and zinc as zinc oxide (ZnO).
Germanium dioxide, which has a boiling point of ~1200°C, can be reduced in the presence of coke to germanium monoxide (GeO) at ~600°C.

GeO sublimates at 710°C, enabling fuming and subsequent recovery of germanium during roasting.
In contrast, although metallic zinc boils at 907°C, zinc oxide has a significantly higher boiling point of 2360°C, which explains the very low recovery of zinc under the roasting conditions (working temperature of 1200°C).

Furthermore, chemical analysis revealed that zinc was not significantly reduced from the raw slag (8% Zn) to the secondary slag, indicating that much of the zinc remained trapped.

This retention is attributed to the complexation of zinc with other elements in the slag matrix, potentially forming stable alloys that resist reduction and volatilisation under the applied conditions.

The study was conducted on a laboratory scale and provides insight into the different behaviours of germanium and zinc during reduction roasting.

The findings suggest that while germanium can be effectively recovered by volatilisation as GeO, zinc recovery requires alternative approaches or higher temperature/chemical conditions to overcome its thermodynamic stability in oxide or alloyed form.

K. Zitha
University of the Witwatersrand

I am a hardworking individual who manages time and stress well in a fast paced environment. I take pride in doing my work with excellence while ensuring that I deliver tasks timeously. I am flexible in new environments, and I have a demonstrated history of professionalism, and I have good people skills. I am results orientated, attentive to details with the ability to work with no supervision, I improve upon feedback. I possess the ability to use discretion and maintain confidentiality on sensitive and proprietary information. I have a strong work ethic and highly developed communication skills. I have 2+ years working in mining and metallurgical research industry.

Overview of furnace start-up with a case study from the Zimplats smelter expansion project

M. Mutshaeni[1], M. Sitefane[1], P. Lu[1], T. Isaacs[1], F. Stober[2], M. Mosnier[2], G. Mulder[1], T. Kingsley[1], S. Matutu[3], T. Sisya[3]
[1]Hatch, Greenstone, South Africa
[2]Hatch, Mississauga, South Africa
[3]Zimplats, Selous, Zimbabwe

Furnace start-ups are uniquely challenging and differ from routine operations. Due to their infrequent nature, a comprehensive start-up plan that captures (1) lessons learnt and best practice from industry benchmark and (2) empirical performance data is essential. The Zimplats furnace 2 start-up was supported by a Hatch technical assistance team.

A comprehensive start-up plan has several benefits, including the facilitation of informed decisions during the startup process; it calls for tracking of start-up progress against the initial plan; and the identification of upset conditions that may compromise the start-up. The start-up process is divided into phases, each with specific objectives to ensure general crucible, but especially hearth integrity. It is equally critical for post-furnace start-up that sound condition-based monitoring strategies are adopted to mitigate the risk of premature failure modes of new equipment (both the furnace crucible equipment and its ancillaries). This ensures sustainable furnace operation at nameplate capacity and ensures that the industry benchmark campaigns are achieved or exceeded.

This paper provides an overview of a furnace start-up with particular focus on Zimplats 38 MW Furnace 2 start-up conducted from August to October 2024. This start-up marked a significant milestone in the Zimplats' smelter expansion project. The overview highlights several start-up aspects which include demonstrating the value of a comprehensive start-up plan as well as the importance of risk-based trading-off of integrity and schedule pressures. Several challenges encountered, lessons learnt, and success factors are highlighted throughout this paper that will prove valuable for future furnace start-ups.

Integrated design of a converter off-gas system

J.P. van Dyk
Hatch, South Africa

Hatch provided full EPCM services to Zimplats for the US$ 400 million Smelter Expansion and SO_2 Abatement Project at the Selous Metallurgical Complex, South-West of Harare, Zimbabwe. The smelter expansion scope included the installation of a new electric furnace, two new Peirce-Smith converters and primary and secondary off-gas systems to serve the new furnace and converters. Implementation of an acid plant to convert the SO_2 gas that is generated during the PGM smelting and converting processes is integral to the SO_2 abatement system to ensure that the client's facility adheres to the governing environmental regulations. To minimise the capital and operational cost it is required that the acid plant receives high purity SO_2 gas and runs an autothermal process. The inlet temperature and maximum amount of dilution air that is drawn into the primary off-gas system need to be controlled. The capture efficiency of the converter off-gas system needs to be maximised and adhere to the emission limits. A combination of a close sealing water cooled converter primary hood, spray cooler and converter secondary hood was required. An integrated system approach to gas capture efficiency and mechanical design of the converter hoods was adapted. All aspects of the off-gas capturing and heat transfer process were simulated using Computational Fluid Dynamics (CFD). Equipment profiles were developed to ensure that the capture efficiency, dilution air ratio and thermal characteristics were achieved. The CFD off-gas models included the converter geometry where the off-gas originates, converter and primary hood interface, secondary hood, primary hood gas flow channel, spray cooler inlet duct and spray cooler. Heat transfer from the gas to the water-cooled primary hood, inlet duct and spray cooler was incorporated in the CFD analysis to ensure that the required gas outlet temperature is achieved; minimum surface temperatures to prevent acid condensation and identify any hot-spots or areas with irregular flow. The spray cooler profile and nozzle layout was optimised to ensure that the water spray evaporates fully before exiting the spray cooler or impinging on the spray cooler inside surface. The temperature profiles of the primary hood, spray cooler inlet duct and spray cooler were transferred to Finite Element Analysis (FEA) software as input to the structural design of the equipment. Previous failures guided the detailed analysis of specific areas of the primary hood panels. Material selection was based on the process requirements, thermal properties and strength characteristics. Capital budget limitations required the spray cooler design to adopt lower cost 3CR12 stainless steel which is not refractory lined or fully insulated. Fabrication process improvements included stud welding methods as opposed to manual fillet welding of approximately 8000 studs and varying levels of non-destructive testing of critical and less critical areas. Construction planning was incorporated during the design, considering preassembly of the off-gas equipment as far as possible and ensuring that appropriate lifting points were included for the assembled sections. The building design was adapted to facilitate future removal and replacement of the large pieces of equipment.

Jacobus Petrus van Dyk

Engineering Manager
Hatch

Jacobus is a registered professional engineer with the Engineering Council of South Africa. Since 2008 he has been involved in the execution of projects, where he was responsible for the design and procurement of specialised equipment and the management of vendors during the fabrication process. During his time as machine design engineer, he was responsible for the conceptual and detailed design of custom machines and equipment for the petrochemical, rail, mining and metals industries. Recent projects include the Zimplats F2 Detailed Engineering project, where he was engineering manager and his involvement spanned from the feasibility study phase, basic engineering, detailed design, procurement and the final installation and commissioning on site. This involved the initial definition of the required equipment, cost estimation and vendor identification, management of package engineers and designers as well as engineering quality throughout the process.

As continuation to the detailed engineering project, throughout construction and commissioning, he acted as project manager for the Technical Site Support phase.

Risk-based prioritisation of spare parts for smelting furnaces

M. von Delft[1], A. Irvine[2], F. Hannemann[1], D. Naidoo[1], R. Hocking[3], B. Ferrer[2]
[1]Hatch Africa, South Africa
[2]Hatch, Canada
[3]Hatch, Abu Dhabi, United Arab Emirates

This paper discusses a method for prioritising and scheduling requirements for the purchase of critical spares for a smelting furnace, to ease cash flow pressures within a capital-constrained environment. Spare parts requirements are assessed based on their criticality, considering furnace failure modes, risk ratings and equipment supply lead times. Examples from an application of this method for a platinum group metals furnace are provided as a case study.

Compared to isolated failure of a single part, multi-part localised failure of a sub-system is more common in smelting furnaces; thus, a spares prioritisation approach that focuses on entire sub-assemblies becomes more suitable for smelting furnaces than traditional part-by-part methods. Additionally, budget constraints, time constraints and lack of sufficient data prompted the use of a simplified method, presented in this paper, rather than going into the full depth and detail of methods such as FMECA which can be unnecessarily onerous. This simplified method does however necessitate consultation with highly experienced subject matter experts and leverages historical records and benchmarking of typical smelting furnace failure incidents.

Milan von Delft

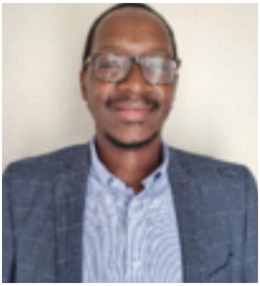
Mechanical Engineer
Hatch Africa

Milan von Delft is a Mechanical Engineer with experience in furnace design, quality assurance, asset performance management, and spare parts supply. He currently serves as an Intermediate Mechanical Engineer at Hatch Africa, supporting PyroTech industries with the Asset Performance Management (APM) group, through condition monitoring via site inspections and data analysis, as well as the supply of spare parts. Previous work has included equipment design of various packages for Pyrotech clients, primarily PGM furnaces, quality assurance of said equipment, technical advisory to construction and commissioning teams, and operational data analysis. His current work focuses on spare parts management, coordination between design and execution teams, client engagement, and equipment design.

Developing process safety management key performance indicators for smelting operations

M. Ndlovu, K.L. Hines, J. Maharaj, N. Dubazana
Valterra Platinum, South Africa

This paper presents an approach to developing Process Safety Management (PSM) key performance indicators (KPIs) with a focus on pyrometallurgical operations. The paper presents an adaptation of mature petrochemical PSM practices, along with other proven PSM methodologies, to the platinum group metals (PGM) smelting environment. The KPIs are tailored to smelting operations, with the objective of advancing PSM dialogue to the benefit of safety in the sector. The methodology begins with a review of established PSM systems and metrics applied in the oil and gas industries as guided by American Petroleum Industry Recommend Practice (API RP) 754 to identify possible extrapolation into pyrometallurgical operations. This is compared with more established mining risk management processes such as Operational Risk Management to focus on Process Safety Unwanted Events around molten metal processes, to identify both existing and new process safety leading indicators. These established pyrometallurgical risks include challenges such as molten material containment, refractory degradation, fuel system failures and corrosive or flammable gas handling systems. The paper concludes by proposing a KPI dashboard to represent leading and lagging indicators for generic benchmarking of process safety performance to support vigilance and continuous improvement. By doing so, pyrometallurgical operations can supplement a reactive stance centred on personal safety with a proactive culture that anticipates and prevents process safety failures, thereby safeguarding people, assets, business, and the environment.



Mkhokheli Ndlovu

Senior Process Engineer, Process Safety Management (PSM)
Valterra Platinum, Process Safety Management

Dr. Mkhokheli Ndlovu is a seasoned process engineer with dual qualifications in chemical and metallurgical engineering, and over 18 years of industrial experience spanning the chemicals and minerals processing sectors. He has a strong track record in applying Process Safety principles to operational plants and executing capital projects, particularly during his decade-long tenure at Sasol Group Technology, where he contributed to plant optimization and led various project phases.

Dr. Ndlovu has successfully managed projects from concept development through feasibility, engineering design, construction, commissioning, start-up, and optimization. Notably, between 2017 and 2023, he led the design, construction, commissioning, and start-up of the first Wet Gas Sulphuric Acid (WSA) gas cleaning technology implementation in a PGM processing facility at Valterra Platinum's Polokwane Smelter, serving as Process Lead and Commissioning Manager (OHSA 16.2 Appointee).

Currently, he is a Senior Process Engineer in the Process Safety Management (PSM) department at Valterra Platinum, where he plays a key role in driving the implementation of PSM across the organization.

Keith Laurence Hines

Senior Manager Process Safety
Valterra Platinum, Process Safety Management

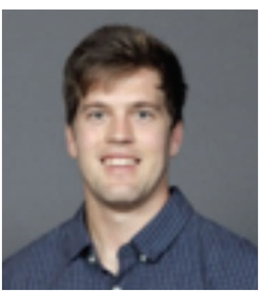
Mr. Keith Hines is an experienced process engineer with over 25 years in the Southern African mining industry across the commodities of gold, coal, potash, diamonds, base metals and platinum group metals. He has covered a variety of technical, project and operational management roles within these commodities.

He has recently supplemented his qualifications by completing a MSc in Process Safety and Loss Prevention in support of his current role as Senior Manager for Process Safety in Valterra Platinum.
Mr. Hines is focused on achieving measurable and sustainable reduction of process safety risk through strong engineering practices and discipline health.

Strategies and evolving practices for modern day smelter off-gas systems design

J. Bezuidenhout[1], G. Mulder[1], A. Hussein[2], P. Baumann[3]
[1]Hatch, South Africa
[2]Hatch, Canada
[3]Hatch, Europe

Off-gas handling systems represent a significant portion of a smelter's infrastructure and capital investment. Such systems and their objectives have become increasingly complex due to evolving environmental regulations, sustainability targets, complex feeds, and pressured economics. These factors demand continuous improvement in the design of new plants, modernization of existing off-gas handling systems, and implementation of emissions abatement projects. This presentation explores off-gas system design approaches by drawing on recent project experience to highlight emerging practices and evolving philosophies.



Driaan Bezuidenhout

Senior Project Engineer
Tenova Pyromet

Driaan Bezuidenhout is a Mechanical Engineer with over nine years of experience in the pyrometallurgy industry. He began his career at Mintek's Pyrometallurgy Division, where he was involved in the design, operation, and optimisation of both AC and DC pilot-scale furnaces. In 2022, Driaan joined Tenova Pyromet as a Project Engineer, where he has been actively involved in the design and delivery of equipment for large-scale furnace installations. His work includes contributions to furnace rebuilds and brownfield upgrades, providing him with valuable exposure to site execution and operational challenges. His current focus includes improving safety, reliability, and process control in high-temperature furnace operations through engineering innovation.

Cost-effective emission control strategies for a changing pyrometallurgical landscape

T. Post, L. de Witt
About Air Pollution, South Africa

Pyrometallurgical operations generate large volumes of high-temperature off-gas that must be cooled and treated to meet stringent emission limits, resulting in significant energy losses and high operating costs. Conventional emission abatement systems treat this thermal energy as a nuisance rather than a recoverable resource. This study proposes and evaluates an integrated co-generation and emission abatement configuration that incorporates high-temperature heat-to-power recovery upstream of conventional gas cleaning units. Waste heat from furnace off-gas at temperatures above 850 °C is recovered via a high-temperature heat exchanger to generate electricity without additional fuel or combustion emissions. Downstream gas conditioning, including particulate removal, quenching, and wet scrubbing, ensures compliance with emission requirements. A simplified mass and energy balance is used to estimate potential electrical output and quantify the reduction in volumetric gas flow to the abatement system. The results demonstrate that integrating high-temperature heat recovery can simultaneously generate electrical power and reduce the size and energy demand of downstream emission control equipment, improving the overall economic and environmental performance of pyrometallurgical off-gas treatment systems.

Theunis Post

Engineering Manager
About Air Pollution

Theunis Post is an accomplished Chemical Engineer with over 28 years of experience, and process optimization. Throughout his career, Theunis has successfully led and managed complex, innovative projects spanning ventilation, mining, and polymer manufacturing sectors. He is well known for his ability to meet, achieve, and often exceed company, customer, and project objectives, consistently delivering high-quality results on time and within budget. Theunis has also served as both project engineer and project manager for various complex installations, particularly in the mining and ventilation industries. His engineering expertise is complex is complemented by an unwavering commitment to environmental sustainability, focusing on developing and implementing advanced solutions that improve air quality and minimize environmental impact. He actively addresses some of the pressing air pollution challenges faced across South Africa and the broader African continent. Beyond technical accomplishments, Theunis finds great satisfaction not only in the successful completion of engineering tasks but also in mentoring and shaping future leaders. His strength lies in his diverse field experience and collaborative leadership style, thriving in dynamic team environments where he fosters engineering excellence and encourages professional growth. As a dedicated mentor and team leader, he continually shares his expertise to build stronger, more capable teams empowered to overcome complex challenges.

Liné de Witt

Junior Chemical Engineer
About Air Pollution

Liné de Witt completed her Bachelor’s degree in Chemical Engineering at the North-West University, Potchefstroom, graduating in 2024. Her studies focused strongly on sustainable process design and air quality management, with an emphasis on industrial emission control. As part of her degree, she worked on a process design project to develop a flue gas desulphurisation (FGD) system for coal-fired power stations such as Medupi and Kusile. This experience gave her exposure to the technical and economic challenges of large-scale SO_2 abatement in South Africa, where stricter regulations and environmental pressures highlight the importance of effective scrubber technologies. In her final year, she undertook an individual research project entitled “*Effect of Binder Type and Curing Time on Biochar Pellet Properties*.” This project broadened her understanding of material science and the potential of bio-based solutions in emission reduction strategies. Her current research interests include the design of cost-effective emission abatement systems and the treatment of scrubber wastewater to reduce secondary environmental impacts. She is motivated to contribute to cleaner production methods and the development of more sustainable industrial operations in sectors such as mining, metallurgy, and power generation.

Competitive and sustainable SO_2 abatement with the WSA process in pyrometallurgy industry

C. Frandsen

TOPSOE A/S, Denmark

The metallurgically industry faces increasing pressure to reduce SO_2 emissions. While treating strong SO_2 gases is standard, handling lean and fluctuating SO_2 off-gases is a future challenge. These gases, which can have both low SO_2 concentrations and be highly fluctuating, present both operational challenges and opportunities. This paper explores the sources of these gases from furnaces and smelters and specific obstacles that may arise when these are to be handled. The paper focuses on efficient methods for dealing with sulfurous off-gases and examines innovative solutions like the wet gas sulfuric acid (WSA) process to enhance sulfur abatement, energy efficiency, and regulatory compliance.

As regulatory authorities tighten emissions standards for the metallurgically industry – such as the stringent SO_2 emission requirements implemented in South Africa recently – there is increasing pressure to improve SO_2 capture across plant operations while maintaining both sulfur recovery and energy efficiency. The drive to reduce greenhouse gas emissions and increase circularity further emphasises the need for innovative solutions to SO_2 control.

In the typical off-gas from the furnaces and smelters there is a wide range of off-gases containing varying amounts of SO_2, with concentrations ranging from low level to several percentage points. High-concentration SO_2 gases are routed to gas cleaning systems and sulfuric acid production units to minimise emissions and recover sulfur. However, lower concentration SO_2 gases are either released into the atmosphere or treated with scrubbers.

Using a scrubber to handle large volumes of low-concentration SO_2 is perhaps the simplest solution, given the lower number of equipment required. However, this leads to sulfur being captured in a by-product of lower value compared to commercial-grade sulfuric acid. Additionally, the chemicals used in this process add significant operating costs, as does the transportation of chemicals and by-products further complicate the operation.

The WSA process represents a viable solution, allowing plant operators to recover sulfur from leaner gas streams while maintaining high energy efficiency and reducing the need for additional chemicals or external energy input. This approach not only enhances plant performance but also supports the metallurgically industry's long-term sustainability goals.

Casper Frandsen

Key Account Manager

Topsoe

Casper started his carrier back in 1991 at TOPSOE, where he took up a position as process engineer for Topsoe's new pilot plant facilities to development Topsoe's technology for different Chemical processes.

In 1995 he changed to the Research and development, where he has worked within different fields: DeNOx technology, Automotive catalyst, Filtration technology, oxidations catalyst, sulphuric acid catalyst and technologies for the sulphuric acid industry and general new technologies within TOPSOE.

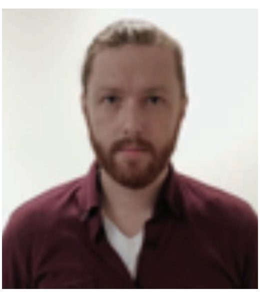
In 2008 he changed to the Technical and Sales group where he worked as Senior Technical Advisor for some years before transferring to sales.

Today he is Key Account Manager for Europe and Africa for the sales of TOPSOE´s sulphuric acid catalyst and TOPSOE´s SO_2 abatement technologies for the metallurgically industry.

Predicting flue gas conditions from bio-based Si production for carbon capture implementation

M.K. Windfeldt[1], G. Tranell[1], V. Andersen[2]
[1]Norwegian University of Science and Technology, Norway
[2]Elkem Silicon Products, Norway

The increased use of biogenic carbon materials and implementation of carbon capture are both recognised as necessary steps in the transition to zero emissions ferroalloy production. In the production of silicon and ferrosilicon metal, low flue gas CO_2 concentration has been a barrier for the latter, as this has an adverse effect on both capital and operational costs. The primary strategy for increasing the concentration will be reducing the furnace air intake, but this is expected to have several secondary effects on both furnace operation and flue gas handling that must be identified and addressed. In particular, the temperature of the flue gas and concentration of key components such as SO_2, PAHs, moisture and troublesome trace elements should be kept under control. As a first step, the composition and energy content of the flue gas after combustion at the charge surface will be predicted using model-based mass- and energy balances. Proximate and ultimate analyses of various carbon materials from literature will form the basis, along with distribution coefficients between the metal/slag, particulate, and gas phases for each element of interest. For various carbon material mixes, ranging from mostly coal and coke to fully biogenic material, the impact of reducing the air intake will be studied. Key operational parameters such as silicon yield and carbon loss will also be included as inputs. Initial results indicate that a significantly reduced air intake is required for the CO_2 concentration to reach above 5 vol%. Increased amounts of biocarbon makes it slightly more difficult as well but has the positive side effect of significantly reducing the SO_2 concentration, even at very low air amounts. The opposite is expected with regards to some unwanted trace elements, particularly alkalis and phosphorous. Flue gas temperatures increase predictably as the air intake is reduced but also show a dependence on the carbon mix, and specifically on the level of moisture and combustible volatiles it contains. The intent behind the model presented in this paper is to highlight gaps in the knowledge of Si flue gas conditions with significance for carbon capture, in the context of increasing biocarbon use. This will inform future experimental work on raw materials and industrial flue gas measurements campaigns, and results from those will in turn be used to improve the model. Finally, this will give insights into the silicon producing industry on the implementation of their strategies for zero emissions metal production.



Magnus K. Windfeldt

PhD candidate
Norwegian University of Science and Technology (NTNU)

Magnus is a PhD candidate at the department of Materials Science and Engineering at NTNU. He holds a MSc from the same department and has experience from several years of research at SINTEF, where he worked and published in the field of industrial energy efficiency and heat recovery. His PhD project started fall 2025 and is part of the FME ZeMe research centre for zero emission metal production. It aims at enabling carbon capture from silicon production flue gas under increasing use of biocarbon reductants.

Modelling of zinc reduction with hydrogen

A. Kotze, E. Nagels, S. Arnout
InsPyro, Belgium

The Dust2Value project demonstrates the feasibility of decarbonising the state-of-the-art Waelz process for recovering zinc from steelmaking waste, specifically electric arc furnace dust (EAFD). The novel process utilises hydrogen to reduce zinc oxide to zinc vapour. This is followed by in-situ reoxidation with water vapour, forming fine zinc oxide particles that exit with the off-gas stream. A valuable co-product is secondary-grade direct reduced iron, which is reusable in EAF steelmaking.

To support process development, various simulations were employed:

- Thermodynamic modelling established the critical operational window for the kiln.

  A coupled kiln model (mass and energy balance) iteratively balanced the three-way interactions among temperature, reaction kinetics, and endothermic reduction heat. This yielded the estimated gas and solid temperature profiles, along with the progress of zinc and iron reduction over the kiln's length. Key outcomes include evaluating the effect of different feed compositions on efficiency and determining hydrogen need and efficiency.

- Computational Fluid Dynamics
  This provided detailed engineering insights, including a temperature map, heat losses, and heat transfer estimates for critical components like the kiln. CFD visualisations of the gas flow trajectory were essential for optimising the gas heating system design.

Simulations will remain crucial during future development and pilot plant operations through the deployment of a digital twin.

Andrea Kotze

Project Manager
InsPyro

An engineer with a strong focus on innovation and modelling within the metals industry since 2015. She obtained a bachelor's degree in Process Engineering from the University of Pretoria in 2014 and her Masters degree in Process Engineering at the University of Stellenbosch in 2024. Currently employed as a Project Manager at InsPyro, a metallurgy consultancy company specializing in providing services to the non-ferrous and ferrous industry, they utilize their technical expertise to develop innovative solutions, optimize processes, and conduct modelling studies to enhance efficiency and productivity.

Fluidised bed reactor tests of oxidised Senegalese ilmenite with varying temperatures and water vapour content studying kinetics

T.P.M. van Kaam, B. Taferner, Dr. M. Tangstad, Dr. S. Lobo, DI Dr.mont. J. Eisbacher-Lubensky
Norwegian University of Science and Technology, Norway

Ilmenite pre-reduction is performed today using carbon materials, emitting carbon dioxide. Moving closer to Norway's 2025 carbon-neutral goal forces changes in today's processes. One way to drastically reduce emissions is to replace carbon materials with hydrogen gas during pre-reduction. Inspired by direct iron reduction, a fluidised bed reactor (FBR) can be used. A lab-scale FBR was used to conduct 15 reduction experiments in H_2 and H_2/H_2O atmospheres. A Senegalese ilmenite ore was oxidised in a muffle furnace, then reduced at temperatures varying from 625 to 1000 °C. The H_2O content was varied from 0 to 10 vol%. From the experiments, it was found that Fe_2TiO_5 reduction to $FeTiO_3$, Step 1, occurs unaffected by H_2O in this vol% range. At 625 and 700 °C, Step 1 showed a significant drop in reaction rates. $FeTiO_3$ reduction to metallic Fe and TiO_2, Step 2, was found to be dependent on both H_2O content and temperature. The $FeTiO_3$ reduction rate decreases with increasing H_2O content and/or decreasing temperature. Distance from equilibrium partial pressures was used as an indication for the driving force of the reaction, $\frac{(p_{H_2}-p_{H_2,eq})}{p_{H_2O,eq}}$

In combination with the apparent reaction rate (R_1,R_2) the collision factors ($k_{0,1}$,$k_{0,2}$) and activation energies (Ea_1,Ea_2) were calculated. Step 1, reduction of Fe_2TiO_5, had an activation energy of 75.1 – 57.9 [kj/mol] with a k0 of 1053 – 165.3 [1/s]. Step 2, reduction of $FeTiO_3$, had an activation energy of 58.7 – 41.5 [kj/mol] and a k0 value of 19.5 – 3.3 [1/s], depending on the data set. An increase in the activation energy for Step 1 reduction was observed in the temperature range 625–700 °C. Above this range, the temperature dependence decreases.

Tristan Petrus Maria van Kaam

Norwegian University of Science and Technology

Tristan Petrus Maria van Kaam attended the Norwegian university of Science and Technology for my BSc thesis. Where he investigated the effect of water vapor on the reduction of ilmenite pellets. Later, he continued at the Norwegian University of Science and Technology for my MSc. Where he wrote his master thesis in collaboration with HySA Infrastructure under Dr du Preez. The research topic was on the effect of oxidation on the pre-reduction of ilmenite with hydrogen gas. During his time in South-Africa he had a short stay at Mintek under the guidance of Dr. Xolisa Goso, where they investigated mass loss of ilmenite from KwaZulu-Natal under an hydrogen atmosphere. Currently he is working as a PhD candidate under the guidance of Merete Tangstad and Stephen Lobo, where they are continuing to investigate the reduction behaviour of ilmenite under a hydrogen atmosphere.

Demolition techniques applied to the 107 m tall smelter converter stack at Palabora Mining Company

C. Coetzee[1], S. Ledwaba[1], R.T. Rathogwa[1], A. Mhondiwa[1], R.B. Khumalo[1], F.K. Mulenga[2], T. Habib[3]
[1]Palabora Mining Company, South Africa
[2]University of South Africa, South Africa
[3]Draco Group, South Africa

In June 2025, Draco Group demolished a 107 m converter stack at Palabora Mining Company after a survey confirmed severe instability. Commissioned in 1960, the stack underwent a single significant refurbishment in the late 1980s. By the time the project began, the concrete shell and internal reinforcement of the stack had deteriorated to the point where its stability could no longer be guaranteed. Survey results by Knight Piésold, a company specialising in geotechnical engineering showed the stack leaned 6° with a corresponding 600 mm deflection from the centre line. This exceeded the SANS 10160 serviceability limits by 22%.

Top-down dismantling and crane-assisted removal were assessed and rejected due to the degree of instability and restricted access to the stack. Instead, a controlled toppling strategy was developed, combining precision blasting with structural engineering measurements. More than 400 blast holes were drilled to form a failure plane. A hinge was formed using a diamond rope cut to guide the fall, and additional masonry and steel supports were installed to deal with openings that were left by the ducts entering the stack. Collapse modelling drew on more than 1000 reflectorless survey data points, while thermal drone surveys provided additional information on structural stress. A 300 m exclusion boundary was set around the site and actively monitored. Environmental controls were an integral part of the demolition plan.

The stack was brought down safely within the planned zone, landing with a deviation of less than 20 m. No damage occurred to adjacent infrastructure, and no safety incidents were recorded. Smelter operations resumed within 48 hours, following the reinstatement of the rail lines. Draco Group's achievement as a technical service company sets a new benchmark for specialist demolition across Africa. It showcases how engineering excellence, environmental care, and stakeholder collaboration can align to solve complex problems safely, responsibly, and memorably. The approach provides a clear framework for future high-risk demolitions where conventional dismantling methods are not applicable.

Carl Frederick Coetzee

Section Engineer
Palabora Mining Company

Growing up in the mining town on of Phalaborwa played a significant role in shaping my interest in engineering from an early age. After completing my schooling, I pursued my passion for problem-solving and mechanical systems by enrolling at the North-West University and in 2017, I proudly graduated with a degree in Mechanical Engineering, a milestone that set the foundation for my career.

In 2018 I started my career as a graduate at Palabora Mining Company, being exposed to all the aspects of the business. During the exposure time I found great interest in the more complex construction projects. In 2022 I obtained my Government Certificate of Competency: Mines and Works Mechanical and began working at PMC Smelter as the legally appointed engineer where I continue to contribute to its operations and development.

Over the years, I have had the privilege of working on multiple projects that have tested both my technical expertise and leadership skills. The more noteworthy projects I was involved in includes the construction of a Double Side Blown furnace, waste Head boiler construction, installation of a 3.5MW Turbine Generator and the demolition of a 107m stack, all of which required careful planning, safety management, and teamwork.

I am currently closely involved in the ongoing Retrofit project at the Smelter, an ambitious project aimed at modernizing and improving efficiency in operations and reducing the emissions, heading to a more sustainable future.

My work has also taken me beyond South Africa’s borders. I had the opportunity to travel to China, where I gained valuable insights into oxygen plant technology—knowledge that I have been able to bring back and apply within our local Smelter.

Engineering, to me, is not just a career but a calling. Each challenge is an opportunity to learn, innovate, and contribute to the growth of both the industry and my community. Working at Palabora Mining Company, I remain committed to applying my skills to ensure that the smelter continues to thrive while also striving for sustainable practices and zero harm.

Three-stage approach in rehabilitation work of the smelter hyperbolic cooling tower at Palabora Mining Company

R. Van Rensburg[1], P.J. Junius[1], R.R. Rathogwa[1], S. Ledwaba[1], S. W. Ngobeni[1], A. Mhondiwa[1], R.B. Khumalo[1], F. Mulenga[2]
[1]Palabora Mining Company, South Africa
[2]University of South Africa, South Africa

The smelter power plant at Palabora Mining Company (PMC) was commissioned in 1964. This power plant incorporates a hyperbolic cooling tower that is essential for dissipating heat from the cooling water system. The cooling tower serves key equipment: the turbine generator condenser and the blowers. The structural integrity of the hyperbolic cooling tower is so critical to the continued operation of the smelter that a series of engineering assessments have been carried out to address its progressive deterioration.

A stability study done in 2009 formed the first rehabilitation programme that identified wind-induced stresses on the ageing shell as the main contributor to loss of structural integrity. As a result of this, stiffening rings were installed to enhance resistance against wind shear. The second rehabilitation programme happened in 2017 where further investigation revealed significant deterioration of the concrete support columns that then led to the implementation of a reinforcement design incorporating steel beams. In 2023, a comprehensive structural assessment concluded that all compromised concrete columns required replacement with steel beams. In this latest programme, rehabilitation measures entailed the enlargement of plinths to accommodate steel base plate knuckles, the reinforcement of the lower shell with 100 mm of additional concrete and steel mesh, the thickening and protective coating of the outer wall, and the repair and coating of all internal columns.

Following these interventions, the cooling tower is now fully supported by steel columns, with all weakened concrete supports removed. The three-stage rehabilitation approach programme has restored structural stability and has extended the operational lifespan of the cooling tower beyond the current life-of-mine. Scheduled routine maintenance of the cooling tower will continue, while the involvement of the external parties will be arranged at certain intervals as and when required.

Rowan Hugh van Rensburg

Projects Superintendent
Palabora Mining Company

My project management career began back with Canon SA where I got an extensive knowledge on mechanical engineering. During this tenure I obtained my Diploma in project management with Damline Business School.

To broaden my experience and knowledge I joined Siemens SA (Head office in Germany).

I spent many years in and out of Germany training in house on mechanical, electrical, and instrumentation engineering principles. I finally was included in a global pool of professionals utilised for worldwide Siemens projects and installations.

Later I joined Knight Piesold Consultants based in Phalaborwa where I got extensive experience on mostly civil projects from roads to water dams including tailings dams. I was introduced to PMC's project engineering department which I later joined. At Palabora Mining company, I have spent my last 15 years to date involved in all engineering disciplined projects of all budget sizes. In total I have in the region of 38 years of project management experience within all engineering disciplines.

Tap-holes – Key to performance … 2026 update

L.R. Nelson[1], S. Ritchie[2]
[1]Pyro One (Pty) Ltd, South Africa
[2]Hatch, South Africa

A decade ago, the critical importance of tap-hole design and management for furnace performance and longevity was highlighted across both ferrous and non-ferrous systems. This paper provides an updated perspective on key design, operational, and equipment developments that enhance fundamental understanding of these core elements, while also emphasising differences between industry commodity types.

Topics addressed will include:
- Advances in automated tap-hole opening and flow control, including drilling and oxygen lancing technologies.
- The influence of mudgun closure practices, with particular focus on the selection, quantity, and composition of tap-hole clays.
- Increased attention on slag tap-hole tapping and post-tap-hole launder operations, areas that have historically received insufficient focus despite their associated risks.

Where applicable, these discussions will be supported by model animations and operational videos, in considering industrial equipment and operational practices. The paper will place special emphasis on emerging systems that advance the industry toward fully automated, remotely controlled tapping processes—removing personnel from hazardous areas while maintaining reliability in the continuous tapping demanded by furnace operations.

Basic operating principles of furnace tapping equipment

E. Grant
Dango and Dienenthal, South Africa

The furnace tap-hole and the related tapping activities are a key component of the successful and safe operation of a smelting operation. By taking advantage of the advancements present in the modern tapping equipment, operator safety, tap-hole lifespan, tapping consistency, and furnace availability can all be optimised. In order to make the most of the equipment available to the operation it is key for all parties involved in the operation, maintenance, and adoption of the equipment to understand both the makeup of the equipment as well as the necessary steps and procedures involved with its operation. By addressing the functionality and operation of the equipment in a 'back to basics approach', this paper aims to assist all parties in the operation and optimisation of their furnace tapping equipment, with a focus on tap-hole management and extension of tap-hole life.

Evan James Grant

Design Engineer
Dango and Dienenthal Southern Africa

I am a young designer currently employed by DDSA. I have grown up in the furnace and smelting industry in South Africa, with work exposure for Samancor Chrome. I have since worked for a project engineering company specialising in the furnace industry, and gained exposure to several smelting operations across the country.

Development of a blister copper tap-hole for flash furnace operation

G.F. Marx
Tenova Pyromet, South Africa

Tap-hole operations are critical to the safe and efficient performance of flash furnaces. Their success depends on the integration and optimisation of several factors, including tap-hole design, component fabrication, installation, process conditions, tapping practices, and maintenance strategies. This paper presents the development and implementation of a blister copper tap-hole design tailored for a direct-to-blister flash furnace. The design prioritises operational safety, process compatibility, structural and thermal integrity, maintainability, and monitoring, while supporting increased throughput.

The tap-hole was engineered to cope with high thermal and mechanical stresses while maintaining compatibility with existing furnace interfaces. Key design features include optimised geometry, enhanced cooling strategies, and robust material selection. Installation and maintenance procedures were refined through iterative feedback from operational data, resulting in improved campaign longevity and safety. Real-time monitoring and site-specific performance metrics were used to validate the design and guide procedural adjustments.

Insights from several years of site operation have informed ongoing improvements. The paper concludes with key lessons learned and recommendations for future development, contributing to the broader understanding of tap-hole optimisation in high-intensity copper smelting environments.

Frik Marx
Principal Engineer, Base Metals
Tenova Pyromet

Frik Marx is a Principal Engineer in the Base Metals Group at Tenova Pyromet, with over 30 years of global experience in the pyrometallurgical industry. His career spans a diverse range of roles, including project management, equipment design, technical marketing, and the development of innovative pyrometallurgical technologies. A qualified mechanical engineer, Frik has contributed to numerous international projects through both permanent and consulting engagements. He formally joined Tenova Pyromet in 2023, bringing with him a wealth of expertise in furnace systems and high-temperature engineering applications.

Accelerating green ironmaking: Emerging R&D methods, progress, and challenges

Y. Shen
University of New South Wales, Australia

Process design and control play a crucial role in the development of green ironmaking technology. Most processes and reactors are very complex, remaining as black boxes for centuries, as they usually involve not only multiphase flows but also heat and mass transfers related to chemical reactions and their interactions – the so-called reacting flow. The operations must be redesigned and/or optimised in order to be competitive and sustainable, particularly for low-cost ironmaking decarbonisation. This will need continuous innovative research and development. Computer simulation and modelling, supported by data and experiments, have emerged as an indispensable adjunct to the traditional modes of investigations for the design and optimisation of processes and reactors for green ironmaking, including blast furnace innovation using renewable injections (including biochar and hydrogen-rich gas) and sustainable burdens (including ferro-coke, bio-coke and bio-iron ore products), shaft furnace, electric smelting furnace, and fluidisation ironmaking. In this paper, the author will report his core research on process modelling of reacting flows and its applications to a range of green ironmaking processes and reactors, followed by a review of challenges. Several examples of industry applications will be used for demonstration. The modelling works are indeed helpful to understand fundamentals and optimise and develop new, cleaner, and more efficient green ironmaking technologies with measurable industrial outcomes.

Yansong Shen

Professor
University of New South Wales

Dr Yansong Shen is a full Professor in the School of Chemical Engineering at the University of New South Wales (Tenured). He is a Fellow of the Australian Academy of Technological Sciences & Engineering (ATSE) and the Chair of Mineral Resource Forum of ATSE. He is the Director of a five-year ARC Research Hub (A$13M). He obtained his BEng and MEng degrees from Northeastern University (China) and his PhD degree from UNSW. He initiated and is leading the 'UNSW SCoPE Lab for Green Metals' (www.scope.unsw.edu.au). He published over 270 peer-reviewed papers in top-tier journals, secured 14 ARC and >40 highly competitive research grants from national and international funding agencies, in total over AUD A$130M, established industry engagements in Australia and overseas, and won several honours and highly-competitive national fellowships e.g. ARC APDI Fellowship (2012) and ARC Future Fellowship (2019). His group designed and scaled up several new technologies, including new low-carbon ironmaking technologies, iron ore and coal/biomass processing and upgrading, and reactor design. Many of them have been patented, implemented and practised in industries with measurable benefits. He was selected as the President of the Australasian Particle Technology Society, and the Fellow of the Royal Society of New South Wales, the Fellow of the Institution of Chemical Engineers (IChemE), and the invited/plenary speakers at tens of international conferences.

Advancing sustainable ironmaking: design, modelling, and TRL development of a containerised hydrogen plasma smelting reduction furnace

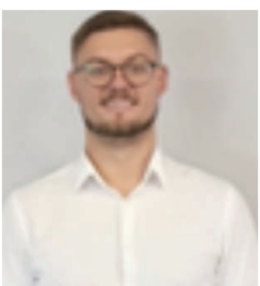
T.K. Wickham[1,2], S.P. du Preez[2], D.G. Bessarabov[2], A.J. Laubscher[1], M.L. Ramagadza[1], S.C. Louw[1], E.L.J. Kleynhans[1]
[1]Metix Pty Ltd (SMS group GmbH), South Africa
[2]Hydrogen South Africa (HySA) Infrastructure, South Africa
North-West University, South Africa

The global transition toward low-carbon iron and steel production has accelerated the development of hydrogen-based reduction technologies. Hydrogen Plasma Smelting Reduction (HPSR) offers a carbon-free smelting pathway capable of treating fine, low-grade, or pre-reduced iron ores without the need for carbon reductants. This paper presents the integrated design, modelling overview, and Technology Readiness Level (TRL) advancement of a 100 kVA containerised HPSR test unit engineered to simulate near-industrial smelting conditions on a TRL 5-6 pilot scale.

The furnace is designed for continuous feeding at 18–20 kg/h, with 60–80 kg batch tapping capability, enabling realistic assessment of slag formation, melt dynamics, hydrogen utilisation, and reduction behaviour. A dynamic mass- and energy-balance simulation framework was developed to guide furnace design parameters, predict transient system responses, and assess the influence of feed distribution, pre-reduction degree, slag chemistry, and off-gas recycling strategies.

Model results demonstrate strong alignment with published experimental trends and reveal that hydrogen efficiency is highly sensitive to ore metallisation, feed location, and the use of recycled off-gas. The containerised test unit also incorporates ATEX-compliant hydrogen safety systems, automated electrode control, and flexible feed systems (hollow-electrode, peripheral arc feeding, or side-wall slag feeding).

The integrated design–modelling approach advances HPSR from laboratory-scale (TRL 4) towards bench- and pilot-scale validation (TRL 5–6). The unit will provide critical empirical data for validating reduction kinetics, quantifying hydrogen consumption, and studying scalable process behaviour under industrially-relevant operating conditions. The outcomes support the broader move toward sustainable pyrometallurgy and green steelmaking.



Tristan Wickham

Process Engineer / PhD student
Metix Pty Ltd (SMS Group)

Tristan Wickham is pursuing his PhD at the North-West University with a Metix bursary, working to raise TRL for hydrogen plasma smelting reduction. His thesis covers the electrical, mechanical, process design and modelling, as well as operation of a 100 kVA DC test furnace. Tristan holds a BEng in Chemical Engineering from the University of Pretoria (2022) and a BEng Honours in Control Engineering (2024).

Reduction of vanadium titanomagnetite using hydrogen gas

L. Otto, S.P. du Preez, E.L.J. Kleynhans
Metix (SMS group), South Africa

Vanadium titanomagnetite (VTM) is a valuable polymetallic iron ore containing appreciable amounts of iron, vanadium, and titanium, along with minor elements such as chromium, nickel, and cobalt. Global reserves of VTM exceed 40 billion tons, with significant deposits located in China, Russia, South Africa, the United States, Canada, Norway, Finland, India, and Sweden. These ores are of considerable industrial relevance, serving not only as a source of iron for steelmaking but also as a primary feedstock for vanadium and titanium extraction. Typically, VTM ores undergo beneficiation to produce concentrates enriched in vanadium and titanium, which are subsequently processed according to their specific elemental compositions.

This paper explores the hydrogen (H_2) gas-based reduction of as-received South African VTM ore, aiming to demonstrate a promising low-carbon process route for industrial application. The reduction pathway involves a series of thermochemical reactions:

Hematite (Fe^{3+}) is first reduced to magnetite.

$3Fe_2O_3 + H_2 = 2Fe_3O_4 + H_2O$, $\Delta H° = 1.52$ kJ

Magnetite is then reduced to wüstite (Fe^{2+}).

$Fe_3O_4 + H_2 = 3FeO + H_2O$, $\Delta H° = 78.6$ kJ

Wüstite is reduced to metallic iron.

$FeO + H_2 = Fe + H_2O$, $\Delta H° = 23.2$ kJ

Ilmenite ($FeTiO_3$) commonly occurs as a secondary phase in VTM ores and is reduced to metallic iron together with titanium oxides:

$FeO.TiO_2 + H_2 = TiO_2 + Fe + H_2O$, $\Delta H° = 45.4$ kJ

Following iron oxide reduction, the hydrogen-treated VTM can be further beneficiated to recover titanium and vanadium oxides for downstream processing.

In this investigation, VTM ore lumps were selected to evaluate the effectiveness of hydrogen penetration and reduction within dense ore structures. Particular attention was given to intra-lump gas diffusivity (for H_2 and H_2O) and the extent of decrepitation during reduction.

Experiments were conducted at 900°C, 1000°C, and 1100°C for durations of 5, 15, 60, and 120 minutes using pure hydrogen gas. The reduction progression and phase transformations were characterised using scanning electron microscopy, X-ray diffraction, and Rietveld-derived phase fractions to determine metallization. Metallization degrees and associated mass losses were quantified to assess the efficiency of hydrogen reduction under varying thermal and temporal conditions. To assess the handling integrity of the reduced VTM lumps, their compressive strength and abrasion resistance were also evaluated.

The findings provide valuable insights into the reduction kinetics of run-of-mine VTM ore and establish a foundation for evaluating its suitability in hydrogen-based direct reduction technologies aimed at sustainable iron and steel production.

Lize-Mé Otto

Masters student
Metix (SMS group)

Lize-Mé Otto is a Master of Engineering (M.Eng) student in Chemical Engineering at HySA Infrastructure, North-West University (Potchefstroom campus). She obtained her Bachelor of Engineering (B.Eng) in Chemical Engineering degree in 2024, where she was awarded the best final year project in the Faculty of Engineering. Her current research focuses on the design and establishment of a fluidized bed reactor for the prereduction of ferrous ores, contributing to hydrogen-based reduction technologies for sustainable steelmaking.

Upgrading of ferruginous manganese ores by hydrogen-rich reduction for the ferroalloy industry

D.A. Barrett[1], M. Tadie[1], B. von der Heyden[1], R. Cromarty[2]
[1]Stellenbosch University, South Africa
[2]University of Pretoria, South Africa

This paper investigated the prereduction of ferruginous manganese ore from the Nchwaning mine by isothermal reduction between 650 and 1050°C. The treated ore underwent subsequent magnetic separation to upgrade the Mn/Fe ratio and manganese grade so that the ore can be used as high-quality ferroalloy feedstock. The ore contains recoverable manganese but is penalised by elevated and complex iron content. There is a high degree of mineralogical variability found in the ore. Iron is present both as hematite and in solid solution within manganese minerals such as bixbyite, braunite, and braunite II. A hydrogen atmosphere was used in this study as it is sufficiently reducing to produce metallic iron that can be separated magnetically. Lime and silica additives were investigated to determine their influence on Fe reduction kinetics and globule formation, which impacts the separability of Fe and Mn. Optical microscopy and SEM analysis of the treated material revealed distinct metallurgical behaviour between iron liberated from hematite – forming larger globules (50 to 600 μm) – and iron reduced from Mn-hosted phases, which formed smaller globules (0.1 to 2 μm). Relatively milder reducing conditions achieved the highest Mn/Fe ratio of 4.52 and a Mn grade of 57 wt.%. While below the desired target specification (Mn/Fe of at least 7.5 and Mn grade of at least 44 wt.%), this can still be met by blending the product stream with other low-grade Mn ores that contain minimal Fe. These findings highlight the potential for the upgradation of ferruginous manganese ore.

Daniel Anthony Barrett
Meng (Chem) Candidate
Stellenbosch University

Daniel Barrett is currently pursuing a master’s degree in chemical engineering, specialising in pyrometallurgy and extractive metallurgy. He graduated with a bachelor’s degree in chemical engineering from Stellenbosch University in 2023, where he was awarded the SAiChE Silver Medal for best final-year student in the Department of Chemical Engineering. Daniel’s ongoing project focuses on the green beneficiation of ferruginous manganese tailings from the Kalahari Manganese deposit.

Slags in Mn- and Si-ferroalloy furnaces

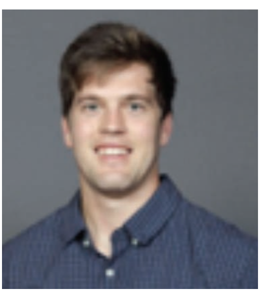
M. Tangstad
Norwegian University of Science and Technology, Norway

Slag in Mn-ferroalloy furnaces is an important part of the process, as the main part of the oxidic raw materials will produce a primary slag when reaching high temperatures. The liquid slag will be reduced, and metal will be formed. In the Si-ferroalloy process, the process is different. In this process the Si-raw materials are quite pure, and only percentages of trace elements will be present. In the molten SiO_2, the trace elements will be enriched in mass as the SiO_2 is reduced, and at a certain stage this will also be a slag containing mainly SiO_2-CaO-Al_2O_3. The main aspect is the reduction reaction to metal, which for FeMn slags are determined by the solid MnO phase. For SiMn and Si-ferroalloy slags the slag is completely liquid. The reduction from Si-ferroalloy slags needs however more than 1800°C while SiMn can be produced around 1600°C. The reduction rate is also very dependent on the carbon materials, and it is seen that for SiMn production charcoal gives a lower reaction rate due to less S content. The slag flow is also important for the operation. In the reduction zone the slag must be able to flow through the coke bed. In other parts of the furnace, the slag will form inactive zones, and examples of that are SiO_2-CaO-Al_2O_3 slags at the walls and bottom of the Si-ferroalloys furnaces, and the MnO layer in Mn-ferroalloy furnaces. Both found during industrial excavations. Lastly oxidic materials can be accumulated in the furnace if not dissolved in the slag, like quartz particle both in SiMn and in Si-ferroalloy furnaces. Slag in Mn- and Si-ferroalloy operation was studied in the Recursive project with the Norwegian ferroalloy industry, and this paper will discuss the work done on these topics.

Innovative solutions for slag tapping control and safety

D. Bezuidenhout, G. de Villiers, H. Joubert
Tenova Pyromet, South Africa

Slag tapping remains one of the most hazardous and operationally sensitive activities at metallurgical furnaces, requiring a balance between reliable process control and uncompromised operator safety. Tenova's SlagFlo™ device represents a significant advancement in the control and management of slag tapping operations within pyrometallurgical processes. Designed to precisely regulate the slag flow rate, SlagFlo™ enables optimal performance for downstream processes such as spinner-based mineral wool manufacture and slag granulation. The device is engineered to provide both controlled closure during regular tap-hole operations and rapid emergency closure in the event of tapping equipment failure, ensuring continuous safety and operational integrity. SlagFlo™ features seamless integration with the slag tap-hole faceplate and incorporates a robust construction that delivers exceptional durability and long campaign life. The SlagFlo™ system is designed to operate in harsh thermal environments and can be configured with either hydraulic or electromechanical actuation to suit site-specific requirements. With its application-optimised design philosophy, SlagFlo™ offers metallurgical plants enhanced flexibility, reliability, and downstream process control. This presentation outlines the design philosophy behind SlagFlo™, its key technical features, and the embedded safety considerations. Practical insights into its implementation and impact on furnace tapping practices are also discussed, demonstrating how improved slag control can enhance both operational reliability and safety outcomes in modern metallurgical plants.



Driaan Bezuidenhout

Senior Project Engineer
Tenova Pyromet

Driaan Bezuidenhout is a Mechanical Engineer with over nine years of experience in the pyrometallurgy industry. He began his career at Mintek's Pyrometallurgy Division, where he was involved in the design, operation, and optimisation of both AC and DC pilot-scale furnaces.
In 2022, Driaan joined Tenova Pyromet as a Project Engineer, where he has been actively involved in the design and delivery of equipment for large-scale furnace installations. His work includes contributions to furnace rebuilds and brownfield upgrades, providing him with valuable exposure to site execution and operational challenges. His current focus includes improving safety, reliability, and process control in high-temperature furnace operations through engineering innovation.

Tapfloor safety with automation solutions

D. Rotthoff
TMT – Tapping Measuring Technology GmbH, Germany

Tapfloor operations in blast furnaces, non-ferrous smelters, and ferroalloy smelters remain among the most hazardous areas of heavy industry. On the tapfloor, operators are exposed to molten metal, sparks, fumes, high thermal loads, and repetitive physical strain. Despite strict safety protocols and personal protective equipment, incidents still occur, highlighting the limits of conventional safety management. A new paradigm is required: 'If there is nobody on the tapfloor, nobody can be injured.'

This paper outlines a structured pathway toward zero accidents through progressive automation of tapfloor operations. Three implementation levels have been defined.

The mechanisation of tap-hole opening and closing removes direct human exposure from the most dangerous tasks while process repeatability and consistency improve. This milestone has already been successfully implemented at multiple smelters. Customers report both safety and process benefits.

Level 2: Advanced Tapping Automation.
Building upon the use of tapping machines, the next step involves video-assisted and fully automated tapping procedures. Operators supervise operations remotely from a control room with cameras and monitoring systems, eliminating the need for close proximity to molten metal. This reduces accident risks, lowers stress, and improves working conditions, making tapfloor work more attractive for skilled staff. Automation also minimises variation in operator behaviour, leading to longer maintenance intervals of machines and a more predictable tapping process. Customer feedback confirms significant safety improvements and higher operator satisfaction.

Level 3: Auxiliary Work Automation.
Beyond tapping itself, auxiliary activities such as rod changing, clay loading also carry risks. In addition oxygen lancing cannot be avoided in all cases and comes with high level of risk. To address this, a compact automated lancing device has been developed which can be integrated into existing installations.
This automated lancing unit has been successfully tested and can be installed as an add-on or standalone solution. By shifting these operations from tapfloor to the control room, operators spend less time in hazardous environments. A further dimension is the use of digital twin training platforms, which allow personnel to practise procedures virtually, building competence without exposure to risk.

Results and Experience.
Field implementations in blast furnaces, non-ferrous smelters, and ferroalloy smelters demonstrate tangible results: accidents and near-misses are significantly reduced, process stability improves, and overall operational satisfaction rises. Benefits include consistency, efficiency, workforce well-being, and adaptability.

Conclusion.
The vision of zero accidents on the tapfloor is no longer utopian. Progressive automation—from tapping machines to automated auxiliary tools and digital twin training—shows that safety and productivity can reinforce each other. By systematically reducing operator exposure, smelters move toward safer workplaces while securing operational reliability and competitiveness. The pathway is clear: through automation, every operator is exposed to less risks to return home safely after every shift.

Daniel Rotthoff

Senior Technical Sales Manager
TMT Tapping Measuring Technology GmbH

Daniel Rotthoff is Senior Technical Sales Manager at TMT, where he has worked for over 13 years on automation solutions for tapfloor operations in blast furnaces, non-ferrous smelters, and ferroalloy smelters.

He holds a “Diplom-Ingenieur” degree in Mechanical Engineering and a Bachelor’s degree in Business Administration. Before joining TMT, he gained valuable experience in plant engineering at Paul Wurth. His expertise combines technical knowledge with project and sales experience, supporting customers worldwide in improving safety, efficiency, and moving toward the vision of zero accidents.

Technical application of process safety in smelting: A qualitative roadmap from HAZID to inherently safer

J. Maharaj, K. Hines, M. Ndlovu
Valterra Platinum, South Africa

Smelting operations in the pyrometallurgical industry involve high-energy processes, driven by temperatures often exceeding 1000°C, that promote melting and chemical reaction, producing separable molten phases into which elements selectively partition. These conditions make smelting inherently high-hazard, necessitating a rigorous and systematic risk analysis framework that supports both the safe design of new installations and the reliable operation of existing facilities. For existing facilities, a phased implementation pathway is proposed, linking risk-tolerance targets, leading barrier-health indicators and human-factors optimisation of high-risk interfaces such as tapping. Despite these demands, implementing a comprehensive process safety management programme in smelting is often constrained by reliance on legacy occupational health and safety systems that are oriented towards personal-safety outcomes rather than the control of complex, high-temperature major-accident hazards. This paper applies process safety management principles to smelting operations and presents a qualitative toolkit, including smelter-specific hazard identification (HAZID) to define credible low-frequency, high-consequence scenarios and their initiating mechanisms; bowtie analysis to structure controls and interrogate their performance; and inherently safer design to reduce major-accident hazard potential at source. This toolkit drew on a typical smelting flowsheet with a broad hazard envelope based on a focused review of smelter technology. The analysis revealed three concentrated risk clusters: steam explosions from molten material – water contact (the most frequent severe outcome), molten material runouts driven by refractory failure, and flammable furnace atmospheres arising from mismanaged firing and electrode breaks. Bowtie mapping indicated a heavy dependence (60%) on administrative barriers. Mechanical integrity failures of cooling elements, refractories, and off-gas components dominated the initiating and escalation paths. Water, prevalent in cooling and quench systems, was the principal escalation vector. Risk is concentrated at transitional interfaces (tapping, molten material handling, feed changes, and start-up) within tightly coupled operating envelopes that narrow the window for stable control. Residual risk identified through HAZID informed the risk reduction themes. Priority was given to removing or minimising hazards where practicable (via inherently safer design); and where elimination was not feasible, preventive and mitigative measures were defined and strengthened.

Julien Maharaj
Manager Process Safety Studies,
Valterra Platinum

I am a registered professional engineer at Valterra Platinum with over a decade of experience improving safety and operational performance in extractive metallurgy. My expertise spans pyrometallurgy, hydrometallurgy, and process safety, with hands-on experience across the entire processing value chain—from concentrators and smelters to refineries. I bring a disciplined, outcomes-focused approach to coordinating cross-functional work and excel at aligning stakeholders to drive practical, technically sound solutions.

Competitive production of green steel and ferroalloys with the ground-breaking SmeltDirect technology

P.H.F. Bouwer
African Rainbow Minerals, South Africa

In response to Europe's push to phase out CO_2-intensive blast furnace technologies, hydrogen has emerged as a proposed solution for decarbonising the steel and ferroalloys industry. However, producers are increasingly recognising that hydrogen-based reduction entails prohibitively high production costs and is ineffective for metallising chromium (Cr) and manganese (Mn) oxides. As a result, hydrogen is unsuitable for producing ferrochrome, ferromanganese, and stainless steel. To address these limitations, African Rainbow Minerals has developed the ground-breaking SmeltDirect technology over more than a decade of research and refinement. This breakthrough enables the smelting of ores – previously restricted to solid-state pre-treatment – using combusted hot gases. The process achieves exceptional energy efficiency by utilising nearly all the chemical energy typically lost in conventional methods.

SmeltDirect presents a cost-effective and sustainable alternative, leveraging biocarbon and recycled carbon as reductants. This positions it as a compelling solution for green steel and ferroalloys.

Impact of EAF slag composition variability on the slag valorisation furnace design

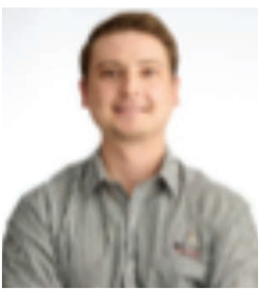
R.K. Dantu, M. Kalenga, S. Louw, E. Kleynhans, I. Geldenhuys
Metix, South Africa

Slags generated in the electric arc furnace (EAF) and ladle furnace (LF) contain significant quantities of unrecovered iron alongside oxide phases that, if suitably stabilised, can be reused in cement manufacture. The concept of a slag valorisation furnace is therefore twofold: to recover Fe-units that would otherwise be lost to waste, and to produce a secondary slag of consistent quality for the cement industry. The main obstacle to realising this potential lies in the large compositional variability of steelmaking slags, which strongly influences furnace performance and product suitability.

EAF and LF slags typically contain CaO, SiO_2, Al_2O_3, FeO, and MgO as principal constituents. The relative proportions of these oxides vary with feedstock quality and operating practice, leading to marked differences in viscosity, liquidus temperature, and reduction potential. Minor components such as MnO and Cr_2O_3, though present at lower levels, further complicate behaviour. MnO alters slag basicity and affects sulfur partitioning, while Cr_2O_3 promotes the formation of spinel phases that increase viscosity and accelerate refractory wear. These factors directly impact both the efficiency of iron recovery and the chemical stability of the residual slag intended for clinker substitution.

Thermodynamic modelling of representative slag compositions highlights the sensitivity of liquid fraction, melting temperature, and reduction equilibria to relatively small compositional shifts. High-FeO slags, for example, increase energy demand and refractory attack, while Cr_2O_3-rich slags restrict flowability and hinder tapping operations. At the same time, the Ca/Si ratio and residual Fe content must be carefully managed to produce a secondary slag compatible with cement chemistry. Failure to control these variables can result in material that is unsuitable for clinker blending or requires costly downstream adjustment.

The paper demonstrates that furnace design must be based not on an average slag composition, but on an operational envelope that accounts for the extremes encountered in practice. Flexible power input, refractory systems resistant to chemically aggressive slags, and operating measures such as staged reduction and controlled flux addition are essential to maintaining stable performance. By linking compositional variability to furnace design and operation, this work outlines an approach that ensures robust Fe-unit recovery while delivering a consistent secondary slag for cement applications



Ryan Keagan Dantu

Process Engineer
Metix

Ryan Dantu is a chemical engineer with a strong foundation in separations technology and thermodynamic modelling, having completed both his bachelor's and master's degrees in chemical engineering specifically focusing on distillation and waste valorisation. He began his career working in the chemical processing industry, where he applied his expertise in process simulation and design to optimize complex separation systems.

After several years in this field, Ryan transitioned into the pyrometallurgical sector, joining Metix, where he now specializes in furnace design and process modelling. His work focuses on advancing smelting furnace technologies, integrating deep thermodynamic understanding with practical engineering design to deliver robust, efficient, and innovative solutions for the metals industry.

Kinetic modelling and simulation of hydrogen reduction of iron from low-grade tailings

I. Kohitlhetse, L. Malimabe
Vaal University of Technology, South Africa

This paper develops and validates a kinetic model for the hydrogen reduction of iron oxides contained in low-grade tailings, enabling simulation from thermogravimetric to reactor scales. Low-grade tailings (hematite–goethite with 35–45 wt% Fe and siliceous gangue were pelletised (Ø 6–10 mm) and reduced in flowing H_2 (0.2–1.0 atm) at 600–900°C. Time-resolved mass loss and off-gas H_2/H_2O were recorded by TGA–MS, while XRD, SEM-EDS quantified phase evolution and porosity. A porous-pellet grain model was formulated in additive-reaction-time form for sequential $Fe_2O_3 \rightarrow Fe_3O_4 \rightarrow FeO \rightarrow Fe$ steps, incorporating mixed bulk/Knudsen diffusion, evolving tortuosity, and sintering-induced pore closure. Heat effects were included through an energy balance with effective thermal conductivity. Global rate expressions first order in H2 with product-gas inhibition captured the data; apparent activation energies were 45±5, 65±5, and 80±8 kJ $\cdot$mol^{-1} for the three steps, respectively. At ≤700°C, kinetics followed surface-controlled reaction mechanism; at ≥800°C, sintering shifted control to concur with the intra-pellet diffusion during FeO→Fe, limiting metallisation. The model matched independent TGA experiments within ±5% conversion and reproduced H_2/H_2O transients, confirming correct water-gas balance and oxygen removal. Packed-bed simulations (1-dimension pseudo-homogeneous with effective properties from the pellet model) revealed strong heat and mass transfer coupling and steep reduction fronts. For 10 mm pellets at 0.6 atm H_2 and superficial gas velocity 0.2 m $\cdot$s^{-1}, >90% metallisation was reached in 14–18 min at 800°C; lowering PH_2 to 0.3 atm or raising SiO_2+Al_2O_3 above 50 wt% lengthened characteristic time by 30–50% via reduced reactive surface and higher tortuosity. Sensitivity analysis identified an operating window of 775–825°C and hydrogen utilisation up to 80% with inlet dew point slightly less than 20°C to suppress reoxidation. Small CaO additions (1–3 wt%) increased porosity and improved final metallisation by 5%. The paper provides physically grounded parameters for scale-up of hydrogen-based retreatment of iron ore tailings, predicting pellet size limits, hydrogen demand, and reactor temperature profiles, and make a room for digitised

Itumeleng Kohitlhetse

Lecturer
Vaal University of Technology

Mr. Itumeleng Kohitlhetse is a lecturer and researcher in Metallurgical Engineering at the Vaal University of Technology (VUT), recognised for integrating rigorous scholarship with industry-aligned problem solving. His career spans teaching excellence, curriculum innovation, and applied research that advances decarbonisation and responsible resource use. His expertise includes curriculum design and development; carbon capture, utilisation and storage (CCUS) using modified low-grade metallurgical slags; beneficiation of low-grade materials; extractive metallurgy and minerals processing of low-grade tailings and slags for sustainable metallurgy; and broader sustainability strategy across metallurgical operations.

At VUT, Mr. Kohitlhetse leads curriculum renewal that aligns learning outcomes, assessments, and laboratory practice with accreditation standards and evolving employer needs. His courses emphasise active learning, safety, ethics, data literacy, and process modelling which seeks to prepare graduates for contemporary metallurgical operations and research. He cultivates students' professional readiness through problem-based projects, structured laboratory skills development, and exposure to real-world case studies that connect scientific fundamentals with plant-level decision making and responsible resource stewardship.

His research investigates engineered metallurgical slags as functional media for CCUS, interrogating reaction mechanisms, sorbent optimisation, and regeneration pathways to enhance CO_2 uptake and durability. By tailoring slag chemistry and microstructure while evaluating techno-economic feasibility and life-cycle performance, he aims to translate laboratory insights into deployable solutions that integrate with existing flowsheets. Complementing CCUS, he advances value recovery from complex feedstocks by developing beneficiation strategies for low-grade ores and secondary resources, and by applying extractive metallurgy and minerals processing to low-grade tailings and slags. His work spans pre-concentration, hydrometallurgical and pyrometallurgical routes, by-product recovery, and waste minimisation, with sustainability metrics embedded from experimental design through to flowsheet validation.

An engaged academic citizen, Mr. Kohitlhetse contributes to teaching quality, laboratory stewardship and safety; mentors students and early-career researchers; and collaborates with interdisciplinary teams and industry partners to frame relevant problems and co-create solutions. Grounded in excellence and service, he prioritises outcomes that are technically robust, economically sensible and environmentally responsible advancing decarbonisation in metallurgical operations and a more sustainable minerals future.

Swelling and lump iron ore breakage in hydrogen gas reduction

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University of Pretoria, South Africa

The transition to hydrogen-based direct reduction of iron ore is one of the critical alternatives to decarbonising the steelmaking industry. It has the potential to reduce carbon emissions significantly compared to the conventional blast furnace operations. However, the implementation of hydrogen direct reduction (HyDR) is challenged by lump iron ore decrepitation, the fragmentation and breakdown of ore during thermal treatment and reduction. Decrepitation poses sever operational risks including poor shaft furnace permeability, increased fines generation, flow blockages and compromised product quality. It is significantly important to understand the underlying mechanisms of decrepitation as the HyDR scales up to meet global decarbonisation targets.

This study employs an in-situ monitoring approach using a linear variable differential transducer (LVDT) displacement sensor coupled with a precision analytical balance system integrated within a controlled atmosphere induction furnace. The LVDT system, positioned to monitor the uniaxial displacement of the lump iron ore sample, provides continuous real-time measurements of the swelling behavior. Concurrently, the balance system tracks the mass changes associated with volatile and oxygen release, allowing for the calculation and correlation with physical degradation. LVDT and balance were directly in contact with the iron ore sample by fused silica rods at the top and bottom, respectively. A gas-based sealing component was designed and installed on the furnace to create a frictionless movement of the fused silica rod. The experimental setup enables simultaneous real-time measurements of the volumetric swelling and mass loss during reduction process under varying hydrogen concentrations and temperature profiles The observed trends in lump iron ore reduction at 800°C, under varying hydrogen concentrations elucidate critical mechanisms for decrepitation, integrating swelling, mass loss and phase transformations. LVDT data reveal initial expansion (peaking at 4-6% normalised height), driven by volatile impurity decomposition and hematite to magnetite transitions. Sample contractions follow due to densification of iron from wüstite, promoted by higher hydrogen increasing the kinetics. Mass loss, reflecting oxygen removal, stabilises post-reduction. Higher reduction degree is observed at higher hydrogen concentrations and incomplete reduction at lower hydrogen mixtures.

The trends inform the decrepitation models, where reduction kinetics predict conversion, as validated by the mass loss as a proxy. Swelling and contraction behaviours parameterise pore volume changes, linking initial porosity to stress induced fragmentation. Dimensional changes quantify expansion or contraction thresholds for decrepitation risks. This model-based framework provides predictive assessment for mineralogical based decrepitation through optimised iron ore selection and operational parameters. This research addresses a critical knowledge gap in HyDR by providing a quantitative understanding of the decrepitation mechanisms and their dependence on process conditions. The in-situ monitoring method developed offers a robust experimental design for evaluating ore quality and optimising process parameters. The findings will contribute to the development of predictive models for ore behaviour in HyDR processes, supporting industrial implementation of low-carbon steelmaking technologies.

Sthembiso Sfiso Mkhize

Ph. D. Metallurgical engineering
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Lump iron ore decrepitation in CO and H_2 atmosphere reduction.

A brief history of South African smelting

R.T. Jones
Pyro Consulting, South Africa

South Africa's large-scale mining industry began with diamonds in 1867, and gold in 1886. This required large amounts of electrical power. Plentiful and cheap electricity made it possible to establish smelters for iron and steel, and ferro-alloys in the early 1900s. This was later extended to the smelting of platinum group metals, as well as ilmenite. More recently, the lack of inexpensive electrical power has hugely constrained the South African smelting industry.

SmeltDirect: Ground-breaking smelting of ores, including lower grades and fines, with hot gasses generated from available chemical energy

P.H.F. Bouwer
African Rainbow Minerals, South Africa

Ore smelting at high temperatures like chrome ore have been deemed to require drawing an electric arc of a few thousand degrees as essential to smelt the ore. Pre-treatment of ores have been limited to the solid state as equipment like kilns cannot handle the burden as soon as melting phases are generated at high temperatures.

This step change enables the smelting of ores, previously restricted to solid-state pre-treatment, using hot gases. The process achieves exceptional energy efficiency by utilising nearly all the chemical energy typically lost in conventional methods. Low grade and fine ores, reductants and fluxes can be smelted cost efficiently. Molten product from the Packed Bed Reactor flows into a Slag Cleaning Furnace where metal recovery is improved, approaching thermodynamic limits, which is substantially higher than conventional processes.

SmeltDirect technology has been fully developed by African Rainbow Metal Technologies (ARMeT) over a period of 13 years and enables the production of chrome and manganese alloys at the bottom of the cost curve. SmeltDirect is also well placed to produce competitive green steel and alloys.

Henk Bouwer (PHF Bouwer)

Executive Technology Development
African Rainbow Minerals

40 years of experience in the ferroalloy industry.

Produced most ferroalloys which include:
Ferrochrome, Medium Carbon Ferrochrome, Ferromanganese, Medium Carbon Ferromanganese, Silicomanganese and Ferrosilicon.
Became the General Manager of a ferroalloy smelter.
Currently the Executive Technology Development at African Rainbow Minerals.
Led the development of the ground-breaking SmeltDirect smelting technology.

Large-scale dual-electrode dc arc furnace technology for the ferro-alloy industry

F.P. Greyling[1], P.H. Swart[2], R Greyling[1]
[1]GLPS, South Africa
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The dual-electrode direct current (DC) arc furnace has emerged as a transformative advancement in ferro-alloy production, offering a scalable and efficient alternative to conventional furnace designs. This technology complements established configurations—including single- and twin-electrode DC, three-electrode AC, and 6-in-line furnaces—by enabling power levels beyond 140 MW. A key innovation is the integration of external electromagnetic arc compensation, which effectively mitigates arc flaring toward furnace sidewalls, enhancing operational stability. Utilising a conventional non-conductive hearth, the system retains proven design benefits while unlocking new performance capabilities. Building on theoretical and pilot-scale validation, the authors successfully converted two industrial-scale FeNi DC furnaces to the dual-electrode configuration. These units operate reliably above 100 MW each, demonstrating the technology's potential for widespread industrial adoption. This development marks a significant leap forward in furnace design, promising improved efficiency, reliability, and scalability for the ferro-alloy industry. The technology is particularly well suited to open-bath smelting operations, offering a viable pathway for the staged conversion of existing submerged-arc furnace infrastructure.

Ruan Greyling

Director
GLPS

Ruan Greyling is an Electrical Engineer with 15 years of experience in the mining and metallurgical industry. Ruan specializes in the development and implementation of DC furnace technology and has played a key role in the field implementation of dual-electrode DC furnace systems. His work focuses on advancing innovative electrical solutions to improve efficiency and reliability in high-temperature metallurgical processes.

Devolatilisation of charcoal and interaction of volatiles with manganese ore

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Sintef Industry, Norway

Charcoal is a potential alternative to metallurgical coke in manganese ferroalloy production due to its lower fossil-based CO_2 emissions; however, its higher reactivity and volatile content may influence carbon consumption and furnace performance. This paper investigates the devolatilisation behaviour of charcoal and the effect of volatile species on pre-reduction of manganese ore.

Experiments were performed using charcoal alone and in mixtures with Comilog and Nchwaning manganese ore. Samples were heated to 800–1200°C under argon while monitoring the offgas composition.

The charcoal released CO_2, CO, CH_4 and H_2 at increasing temperatures. Consumption of CO and H_2 was observed in the presence of ore, implying that volatile species contributed to manganese ore prereduction. Comilog ore showed stronger gas-solid interactions and caused higher charcoal consumption compared to Nchwaning ore. Above approximately 750°C, increased CO formation indicated the occurrence of the Boudouard reaction, leading to increased carbon consumption.

Trygve Lindahl Schanche

Research Scientist
SINTEF

Trygve is a research scientist at SINTEF in Trondheim, specializing in metal production processes. He holds a PhD and MSc in Materials Science and Engineering from the Norwegian University of Science and Technology (NTNU). His research focuses on improving industrial metallurgical processes, with particular emphasis on reducing energy consumption and CO_2 emissions. His recent work includes the use of hydrogen and biocarbon as alternative reductants in manganese ferroalloy production, as well as the integration of innovative pre-treatment and process simulation techniques to enhance sustainability and efficiency.

A trip down the rabbit hole - understanding drainage through a tap-hole

J.E. Olsen
SINTEF, Norway

Furnace tapping—the extraction of molten metal and slag from pyrometallurgical reactors—is a critical step in high temperature metal production. Despite its central role in furnace performance, tapping often exhibits unpredictable and inconsistent behaviour. Such variability contributes to significant maintenance demands in the tap hole region and creates operational challenges for downstream processing. Improving the fundamental understanding of the mechanisms governing tapping has the potential to reduce operational costs and enhance production planning.

From a scientific perspective, metal and slag drainage through a tap hole surrounded by ore and carbonaceous materials can be described as the flow of two immiscible liquids through a permeable particle bed. This is considerably more complicated to study than the textbook example of drainage of a single liquid without the presence of particles. The governing mechanisms are hydrostatic pressure due to gravity (determined by the level of metal and slag in the furnace) which drives the flow of material during tapping, and the configuration of the particle bed which impose resistance to the flow.

The presentation will demonstrate the current state of knowledge and ability to predict tapping rates. This is founded on various numerical modelling methods, water experiments and furnace observations. While advanced computational models can reproduce average tapping behaviour, they consistently struggle to capture and explain outlier tapping events—precisely the phenomena that most motivate industrial stakeholders to invest in tapping research. Several underlying reasons for this gap will be discussed. Ultimately, efforts to fully unravel the governing mechanisms resemble a journey 'down the rabbit hole': complex, often counterintuitive, and continually revealing new layers of physical behaviour.

Thermal dependence of material properties in furnace tapping models: A FeMn case study

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[2]Stellenbosch University, South Africa
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Multiphysics modelling of furnace tapping in submerged arc furnaces (SAFs) has to date largely assumed that the thermodynamic and physical properties of molten slag and alloy are constant with temperature. This paper presents an exploratory investigation into the validity of this assumption for the case of ferromanganese (FeMn) tapping in the duplex manganese smelting process. A computational multiphysics model incorporating multiphase fluid flow, conjugate heat transfer, and flow through porous media was developed using the OpenFOAM® framework and validated against analytical reduced-order calculations. A temperature-dependent material properties dataset derived from thermochemical simulations and empirical correlations was used, and a sensitivity study was conducted comparing models using constant versus temperature-dependent properties. Results indicate that tapping stream temperatures are insensitive to the assumption of constant properties across all material parameters examined. Phase flowrates are similarly unaffected, with one notable exception: the temperature dependence of slag viscosity was found to dominate the response, accounting for the majority of differences arising from the assumption of temperature-dependent properties in general.

Dr Quinn Reynolds

Mintek (South Africa)

Quinn holds degrees in Engineering and Applied Mathematics. He has worked in the Pyrometallurgy Division at Mintek for over 25 years. Mintek is a state-owned research institute serving the extensive mineral and metallurgical processing sector in South Africa. Quinn is also an extraordinary professor in the department of Chemical Engineering at Stellenbosch University.

His expertise includes mathematical and computational modelling of complex coupled phenomena in high temperature processes, and in particular the application of high-performance computing and open source software platforms to pyrometallurgy. His current areas of research include magnetohydrodynamic modelling of electric arcs, multiphysics fluid flow problems in furnace tapping and phase separation, combustion modelling for metallurgical processing, and reduced order modelling for digital twin applications.

Novel PAH-Free carbon-based tap hole material for ferroalloy furnaces: Performance, repairability, and rheological characterisation

P.H. Michels-Brito[1], T. Reis[1], L. Smemo[1], M.A. Bryntesen[1], I. Cameron[2], A. De Pretto[1]
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Tap-hole clays and repair pastes play a critical role in sealing and maintaining the integrity of the tap-holes of ferroalloy furnaces; achieving a strong, stable baked structure is therefore critical for reliable furnace operation. While conventional oxide based clays are effective for basic tap-hole closure, the overall performance in tap-hole repair and refractoriness may be limited, especially during extended tapping campaigns. This can lead to more frequent maintenance and a shorter operational service life of the tap-hole. To address these challenges, Elkem has developed ELTAP® G THL tap-hole paste – a carbon based tap-hole material that is free from polycyclic aromatic hydrocarbons. The material is engineered to provide stable, predictable flow behaviour and enhanced repair capability compared with traditional oxide based clays. There are currently no standardised methods to quantitatively measure in furnace performance of tap-hole pastes and clays. This paper seeks to evaluate lab scale methods for measurement of tap-hole materials, such as the Marshall extrusion test and a parallel plate viscometer test, and correlate these with the operational experience of tap-hole materials and how they perform in an industrial setting. In particular, the combination of shear stress and viscosity measurements enables a more consistent comparison between products and supports a clearer interpretation of in furnace behaviour. A secondary goal of this work is to compare the rheological properties of ELTAP® G THL tap- hole paste with a standard industrial clay material and highlight the stable viscosity and reliable flow of the paste, which makes it a durable, efficient, and safer alternative to traditional oxide based clays for demanding ferroalloy furnace conditions. These rheological differences align with operational observations from industrial furnaces, where carbon based materials have shown improved sealing performance and targeted repair capability.

Paulo H. M. Brito

Research and Innovation Engineer
Elkem Carbon AS

Paulo Henrique Michels Brito is a Research and Innovation Engineer at Elkem, specializing in the development of specialty carbon products and advanced material characterization. He holds a Ph.D. in Physics from the Norwegian University of Science and Technology (NTNU), a Master's in Materials Science, and a Bachelor's in Chemistry from the University of Brasília.

With over 15 years of experience in industrial and academic R&D, Dr. Brito brings a strong interdisciplinary background in chemistry, materials science, and physics. His expertise spans carbon-based materials, clay materials, nanomaterials, and sustainable technologies, with a focus on product innovation.

Transition from tar and resin-bonded to synthetic binder-based tap-hole clays: Health, environmental, and operational performance in ferroalloy smelters

J. Krog, T. Makosa, G. Newall, M. Rösch, J. Vilakazi
Refraline, South Africa

Historically, tap-hole clays have consisted of anhydrous tar that acts as a binder. Although effective, tar-based clays have challenges such as the release of volatile organic compounds into the atmosphere which play a significant role in the creation of tropospheric (ground level) ozone and fine particulates. In addition, these clays may contain benzo[a]pyrene, which is a polycyclic aromatic hydrocarbon that can attach to human DNA and can result in cell mutations and cancerous effects. Some tap-hole clay manufacturers have explored the use of resins as alternative binders. Most of the resins used contain formaldehyde as an ingredient. When formaldehyde is present at levels exceeding 0.1 ppm some individuals experience effects such as eye irritation, coughing, nausea and skin irritations. This paper explores a synthetic binder alternative, which can be used to create a tap-hole clay without any tar or resin present. The experimental procedure included benchmarking the physical and operational parameters to the performance requirements of the tap-hole clay, and the determination of volatile organic compounds emissions of the novel material. Field trials were conducted at selected smelter operations, and the health and safety metrics were measured as part of the trials. The findings indicated that the synthetic binder could be used in the production of green tap-hole clays without sacrificing the operational performance, and meeting the sustainable commitment to the environment, and the health and safety of the workers.

Slag engineering for steel slags stabilisation

M. Guo, S. Huang, A. Mal liet, P.T. Jones, B. Blanpain

KU Leuven, Belgium

Worldwide, approximately 400 million tons of steel slags—including Basic Oxygen Furnace (BOF), Electric Arc Furnace (EAF), and Secondary Refining (SR) slags—are produced each year. However, most of these slags are not yet recycled or reutilised due to inherent instability issues, such as volume expansion and heavy-metal leaching. The recycling and valorisation of steel slags into value-added applications are therefore key to improving the sustainability of the steel industry.

For over two decades, the HiTemp group at KU Leuven has been dedicated to the study of steel slag stabilisation, with the ultimate goal of achieving 'zero waste' in steel production. The group's research activities span a wide range of slag chemistries and processes, including: (1) stabilisation of the C_2S phase in stainless steel and ladle slags; (2) stabilisation of free CaO and MgO in BOF slags; and (3) stabilisation of chromium in ferro-alloy and stainless steel slags.

In this lecture, the authors discuss the various aspects of slag instability, pinpoint the underlying physicochemical mechanisms responsible for volume instability and heavy-metal leaching, and provide a framework to distinguish between these phenomena. Possible solutions to address slag instability in its broadest sense are discussed and proposed through innovations in hot-stage slag engineering, including modifications of slag chemical composition, optimisation of slag cooling, and control of gas–slag reactions (e.g., slag carbonation). These approaches contribute to enhancing the sustainability of the steel industry while significantly alleviating its environmental burden.

Pilot- and bench-scale test work for comparative carburisation of hot metal produced in a DRI smelting process

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Metix Pty Ltd (SMS Group, South Africa)

Metix and the SMS Group have developed a novel solution for a decarbonised steel production route, incorporating an open-bath electric furnace (OBF) for the reductive smelting of highly metallised, blast furnace grade direct reduced iron (DRI). The OBF pilot test campaigns were conducted for technology demonstration on a custom-built test furnaces, successfully tapping hot metal with 2.6–3.0 wt% C depending on whether H□-DRI or natural-gas-based DRI was processed. This was achieved by charging reductant as part of the raw material feed mixture to the furnace. Deep bath pneumatic injection of low sulphur petroleum coke (PetCoke) increased the hot metal carbon content above 4 wt%, confirming the OBF's ability to produce basic oxygen furnace (BOF) ready metal and motivating a focused evaluation of alternative carburisers.

To support industrial deployment of the DRP–OBF–BOF route, a bench scale carburisation study evaluated whether carbon sources commonly used as smelter reductants can also function as carburisers. PetCoke was selected as the industry benchmark due to its long-established high-efficiency performance in commercial post-tap-hole hot metal carburisation, while gas calcined anthracite, hard coal, lignite coke, nut coke, and charcoal were selected as alternative carburisers based on established supply availability, existing handling infrastructure, and, for charcoal, the need to assess renewable carbon performance.

The bench-scale experiments were conducted in a 60 kW induction furnace, using an argon shield to prevent oxidation, with each test performed at 1500°C where 100 grams of alloy was contacted with ~2 grams of carburiser in a high purity alumina crucible targeting 4.5 4.9 wt-%C saturation level in alloy. The tests durations between 10 min (kinetic regime) and 120 min (thermodynamic regime) enabled differentiation between initial dissolution rates and long term saturation behaviour. PetCoke achieved 4.45 wt-%C within 40 minutes and reached a peak of 4.83 wt-%C after 120 minutes. Its superior performance is attributed to its high fixed carbon (>98%), low ash (<0.5%), and a highly accessible turbostratic micro texture, which facilitates rapid dissolution kinetics and a peak carburisation rate of 0.27%C/min. In contrast, other materials showed limited effectiveness, which is attributed to the probable formation of interfacial barriers associated with ash and mineral inclusions. While charcoal reached 4.55 wt-%C after 120 minutes due to its high porosity, its initial rate was low and characterised by high variability. Nut coke (3.98 wt-%C peak), lignite coke (3.79 wt-%C peak), anthracite (3.76 wt-%C peak), hard coal (3.27 wt-%C peak) failed to reliably meet the target of 4.5 wt-%C.

Overall, the comparative results demonstrate that only calcined low sulfur PetCoke achieves the carburisation kinetics and saturation performance required for BOF ready hot metal, while the remaining five materials are constrained by ash related interfacial barriers.

Thabani Ndwandwe

Senior Process Engineer
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Metallurgical Engineer with a strong background in smelting, process optimization, and project execution within the pyro-metallurgical industry. Proficient in the design and commissioning of ferroalloy reductive smelting furnaces.

Career experience includes a long tenure at Richards Bay Minerals as Metallurgy Specialist (Furnaces) and currently employed as a Senior Process Engineer at Metix (SMS Group).

Key expertise spans furnace design, commissioning, furnace efficiency projects, complex data analysis, pig iron processing, and conducting furnace test work involving electrodes, coal, biochar and pilot scale test of new processes. Holds a BSc in Chemical Engineering and a Programme for Management Development (PMD) qualification.

Gasification of coke in a hydrogen-enriched blast furnace atmosphere

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University of Pretoria, South Africa

The steelmaking industry is among the leading contributors to carbon dioxide (CO_2) emissions, and as a result, faces substantial pressure to reduce its environmental impact. The majority of the world's steel is produced from virgin iron ore via the blast furnace (BF) – basic oxygen furnace route, a practice that is expected to remain dominant through 2050. The BF utilises coke both as a fuel and as a reductant. Since the coke generates CO_2, reducing CO_2 emissions depends on lowering coke consumption. Although coke has been partially substituted with alternative fuels, complete replacement remains a challenge because coke is the only fuel capable of providing both burden support and permeability in the BF. Hydrogen (H_2) has been proposed as an alternative reductant to coke, as it produces water (H_2O) instead of CO_2. Hydrogen injections in the range of 5 -15% have already been successfully implemented. The gasification reaction of coke results in significant coke degradation within the BF. This research employed thermogravimetric analysis to examine the kinetics of gasification using both the volumetric model (VM) and the grain model under conditions of 100% CO_2 and a mixture of 85% CO_2–15% H_2O at 1100ºC. In addition, critical coke properties associated with gasification, including the coke reactivity index (%CRI) and the coke strength after reaction (%CSR), were evaluated. Alkali recirculation in the BF, primarily from potassium (K) and sodium (Na) vapours, poses a major challenge as it catalyses the gasification reaction. Therefore, this research also investigated the impact of potassium on coke properties. As efforts to reduce coke consumption in the BF progresses, optimising coke properties becomes increasingly important. Consequently, this study also explored the use of boric acid (H_3BO_3) as a potential additive to enhance coke performance by lowering %CRI and improving %CSR. A comparative study was conducted on four types of coke: as-received coke, coke impregnated with H_3BO_3 (B-coke), coke impregnated with potasium (K-coke) and coke impregnated with both potassium and H_3BO_3 (KB-coke). It was found that the gasification rate in H_2O surpasses that in CO_2, except in K-coke, where potassium reacts with H_2O, thereby decreasing the amount of H_2O available to react with the coke surface. H_3BO_3 decreases the reaction rate under both conditions, whereas potassium enhances it. The GM provides a better fit to the data than the VM, indicating that gasification is limited by the chemical reactions occurring on the coke surface. As expected, %CRI and %CSR showed an inverse relationship: %CRI is higher in H_2O except in K-coke, because K reacts with H_2O; conversely, CSR is lower in H_2O and higher in CO_2, except for K-coke. H_3BO_3 improves the properties of coke, except in K-coke in H_2O, where %CRI increases. Potassium acts as a catalyst for gasification, with %CRI in K-coke being higher than that of the as-received coke.

Bafedile Kgohlo
Student
University of Pretoria

Bafedile Kgohlo is a master's student in Metallurgical Engineering at the University of Pretoria. Her research focuses on reducing carbon dioxide emissions in the blast furnace process. She has a strong passion for pyrometallurgy and refractories.

Reduction and carburisation of iron ore pellets using methanol and glycerol

E. Kemp, R. Cromarty
University of Pretoria, Pretoria, South Africa

The steel industry is under increasing pressure to reduce carbon emissions while maintaining high production efficiency. This study investigates the reduction and carburisation iron ore pellets using thermally decomposed methanol and glycerol as alternative carbon sources. The objective is to evaluate whether these agents are efficient reducing and carburising agents for DRI production.
Pelletised iron ore samples underwent reduction, and carburisation in a vertical retort shaft furnace at 950°C under controlled gas composition conditions. Methanol was decomposed inside the retort furnace, while glycerol was decomposed externally at 950°C and was then fed to the retort furnace. The gas entering the retort furnace is rich in CO and H2.

Initial and final material characterisation was performed using X-ray Diffraction (XRD), Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS), optical light microscopy and LECO carbon combustion analysis. All samples were completely reduced during experiments; only limited carburisation took place.

When compared to industrial DRI, methanol and glycerol have a too-low carbon content. The carbon content needs to be above 1%. DRI produced using methanol had an average carbon content of 0.94%, where one test had a carbon content of 1.02% which is in the industrial standard range. DRI produced using glycerol had an average carbon content of 0.1%. This low carbon content is due to carbon soot forming during glycerol decomposition, which reduces the amount of carbon going into the reduction process.

Eljuné Elsie Kemp

Masters' student, MEng Metallurgical Engineering
University of Pretoria

Eljuné Kemp is currently pursuing her master's degree in engineering, specialising in pyrometallurgy. She completed her undergraduate degree in metallurgical engineering at the University of Pretoria in 2025. At the twenty-first Annual Student Colloquium hosted by SAIMM in 2025 she won third place for presenting her final year project, titled "Eco-friendly Production of Carburised Iron Ore Pellets". She is very passionate about pyrometallurgy. She was raised on a game farm located in Vivo, Limpopo, which instilled in her a strong love for nature, which grew into a passion for sustainability.

Foundations of competitiveness: Turning research into reality in manganese smelting

K. Sutherland
Transalloys Pty Ltd

The manganese ferroalloy industry is facing increasing pressure to improve both competitiveness and sustainability in response to rising energy costs, tightening environmental regulations, and global mechanisms such as the Carbon Border Adjustment Mechanism (CBAM). In recent years, significant progress has been made in fundamental research aimed at addressing these challenges. Notable examples include the PreMa project, which demonstrated the potential of preheating and pre-reduction technologies to reduce energy consumption and emissions in submerged arc furnace (SAF) operations, and the HAlMan project, which explores alternative reduction pathways using hydrogen and aluminothermic processes to enable near-zero carbon production.

While these initiatives have successfully validated key process concepts and metallurgical principles, their translation into commercially viable, industrial-scale solutions remains limited. A critical barrier lies in the design and implementation of robust, reliable, and economically feasible equipment capable of operating under the demanding conditions of continuous ferroalloy production. Challenges such as the transfer of hot pre-reduced material, maintaining process stability, and integration with existing furnace infrastructure highlight the gap between conceptual innovation and practical deployment.

This presentation argues that the foundation of future competitiveness and sustainability in manganese ferroalloy production will depend not only on continued advances in fundamental research, but increasingly on the ability to engineer these advances into operable systems. Key questions are addressed: what must be done to bridge the gap between research and industrial application, how should these solutions be designed and implemented, and what partnerships are required to enable successful commercialisation?

It is proposed that a shift towards integrated development models is required, involving closer collaboration between research institutions, smelters, equipment manufacturers, and engineering contractors. Emphasis must be placed on designing for operability, maintainability, and scalability – supported by intermediate pilot and demonstration systems that de-risk implementation. Through such an approach, the industry can move beyond conceptual solutions and establish practical pathways to achieving both competitiveness and sustainability.

Combined hydrogen and aluminothermic reduction of Mn ores in HAlMan process: Thermochemistry, products qualities, and sustainability

J. Safarian
Norwegian University of Science and Technology (NTNU), Norway

In the new HAlMan integrated process, hydrogen gas and aluminium scrap/dross are used to produce manganese ferroalloys with low energy consumption and carbon footprint. In this process, hydrogen gas is used to pre-reduce manganese ores which contain metallic iron and MnO. The MnO content of this intermediate is further reduced at elevated temperatures by aluminium in a smelting-aluminothermic reduction process, yielding high-Mn alloy and a calcium-aluminate slag. The metal product of the process is manganese, new Mn-Al alloy, ferromanganese, or silicomanganese – depending on the process adjustments. The thermochemistry of the HAlMan process is evaluated in comparison with the state-of-the-art carbothermic process in a submerged arc furnace (SAF). Experimental results of the HAlMan process are presented, and the effect of ore type and process conditions on the quality of the metal and slag products are discussed. It is shown that that the process is flexible to produce a variety of metallic products, and a consumable/valuable slag byproduct. Mass and energy balances calculations are presented, and it is shown that the energy consumption for the process is significantly lower than the SAF process. It is shown that ferromanganese production by this process prevents significant CO_2 emission in a more robust approach with less challenges than the current low-carbon ferromanganese production technology. The implementation of the HAlMan process in pilot scale through the HAlMan EU project is presented, and it is shown how the process products can be used to make commercial metal products such as commercial grades of steels and aluminium alloys.

Jafar Safarian

Professor
Norwegian University of Science and Technology (NTNU), Norway

I did my B.Sc. (1992-1996), my M.Sc. study (1996-1998), in Iron and Steel production, Isfahan University of Technology, Iran. I worked as university lecturer during 1999-2004, at the same university. I did my PhD at NTNU (2004-2007), in the area of Manganese ferroalloys production. I worked as a PostDoc fellow/researcher at NTNU during 2008-2012 and at SINTEF Materials and Chemistry during 2012-2015.

I joined NTNU from August 2015 as adjunct Associate Professor with 20% teaching tasks. In 2016 I became an Associate Professor at NTNU, and a full Professor in 2021. I have supervised several Master, PhD, and PostDoc researchers, and several management experiences in national and international projects.

Hydrogen pre-reduction of different manganese ores in a vertical retort toward demonstration of the HAlMan process

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The HAlMan process is a zero-waste flowsheet for the production of manganese alloys using hydrogen gas and aluminium metal as non-fossil reductants. The process focuses on treating primary and secondary raw materials in a sustainable manner while pursuing decarbonisation of industrial metal production and recycling of by products for secondary application. The hydrogen pre-reduction step of the process can be undertaken in vessels of different designs including vertical retorts, rotary furnaces, shaft furnaces, and fluidised bed reactors. The current study investigated hydrogen pre-reduction of two different manganese ores in a pilot-scale vertical retort. The retort was externally electrically heated, and the hydrogen gas was introduced at the bottom of the retort through a distribution plenum to percolate through a packed bed of coarse particulates. The study evaluated the pre-reduction of Nchwaning and UMK manganese ores, screened to a size class of +6 mm –20 mm, with 100% hydrogen gas under different reaction temperatures and residence times. The paper will present a detailed account of the characterisation of the manganese ores, experimental equipment and methods adopted, and discuss the experimental results obtained with respect to the extent of reduction achieved for each type of manganese ore.

Madinoge Mampuru

Engineer
Mintek

Dr. Madinoge Mampuru joined the Pyrometallurgy Division at Mintek in October 2023 as a postdoctoral research fellow. She has since joined the division permanently as a Research Engineer in June 2024, seconded to the Technology Demonstration Group. She has a PhD in Mechanical Engineering from North-West University and MSc & BSc in Chemical Engineering from the University of the Witwatersrand. Prior to her appointment, Madinoge held various roles in research, including as Project Engineer in Energy Management responsible for conducting energy audits and initiating energy savings initiatives at various companies of iron and steel manufacturing, as well as gold and platinum mining. Madinoge's strong background in applied research and industry has augmented the discipline's efforts in growing competencies in offering value-added commercial and research services aimed towards developing energy and resource efficiency in pyrometallurgy. Her current passions involve applied research to explore and demonstrate the practical use of hydrogen towards decarbonising pyrometallurgy and thus promoting of sustainable metallurgical operations.

Hydrogen reduction of iron and manganese oxides in ferroalloy ores

M.S. Ernst, M. Tangstad
Norwegian University of Science and Technology, Norway

The decarbonisation of manganese ferroalloy production requires alternative 'prereduction' strategies to replace carbon-based reductants. Hydrogen offers a promising option; however, the chemical and physical transformations of manganese ores under industrially relevant, non-isothermal hydrogen and water vapour conditions are not yet fully understood. In this paper, the non-isothermal prereduction behaviour of Assmang Mn ore was investigated in hydrogen and water vapour atmospheres up to 1100°C using thermogravimetry, supported by X-ray fluorescence, X-ray diffractometry, and physical characterisation. The maximum experimental mass loss reached 15.89 mass% in pure hydrogen, in good agreement with the theoretical value, based on stoichiometry, of ~14 mass%. Normalised results show that the extent of mass loss is governed primarily by reducing atmosphere composition, with pure hydrogen achieving >98% of the maximum mass loss across all particle sizes, whereas an 80%-20% hydrogen-water vapour atmosphere was limited to ~80%. Particle size had a minor influence on the final extent of reduction but strongly affected the rate of mass loss. Chemical analysis confirmed substantial oxygen removal, with the oxygen-manganese ratio decreasing from 1.53 in the raw ore to 1.00 after prereduction. Preferential iron oxide reduction occurred at lower temperatures, followed by progressive manganese oxide reduction and carbonate decomposition between 600°C and 800°C. Prereduction was accompanied by particle decrepitation, reaching up to ~60% for large particles in pure hydrogen. These results support hydrogen-based prereduction as a viable pathway towards lower-carbon manganese ferroalloy production.

Margaretha Susanna Ernst
PhD Candidate
Norwegian University of Science and Technology

Margaretha Susanna Ernst is a PhD candidate in the Department of Materials Science and Engineering at the Norwegian University of Science and Technology. Her research focuses on hydrogen-based pre-reduction of manganese ores as a sustainable alternative to carbon in ferroalloy production, with emphasis on thermodynamics and kinetics. She holds a Bachelor's and Master's degree in Chemical Engineering from the North-West University, South Africa, where she worked with Hydrogen South Africa. Margaretha has published on hydrogen metallurgy and presented at international conferences, contributing to the development of low-carbon metallurgical processes.

Forged resilience: A retrospective on the Furnace Tapping conference series (2014–2022)

J.D. Steenkamp
Vale Base Metals, Canada

Furnace tapping sits at the intersection of art, science, and engineering, yet for decades it lacked a dedicated scholarly platform despite its central role in the safety, performance, and longevity of pyrometallurgical furnaces. The Furnace Tapping Conference series—initiated in 2014 and held again in 2018 and 2022—was established to address this gap by fostering focused technical dialogue and strengthening collaboration between industry, academia, and technology providers. This paper presents a retrospective analysis of the series, examining its evolution, research contributions, and influence on the development of furnace tapping knowledge over nearly a decade. Drawing on 65 published papers, authorship and collaboration trends, and citation impact, the review highlights the emergence of furnace tapping as a cohesive research domain supported by systematic documentation, modelling advances, industrial surveys, and technological innovation. Key themes include tap hole design and maintenance, monitoring and sensing, modelling and risk management, operational safety, and equipment development – alongside insights from coordinated international research initiatives. The paper concludes with reflections on how the conference series catalysed problem driven engagement within the pyrometallurgical community and considers opportunities for future innovation, particularly in the context of decarbonisation and evolving industrial challenges.

Life cycle assessment of a ferrochrome smelting complex: A modelling framework for air and water heavy metal emissions

S.J. Baumgartner[1], A.V. Cherkaev[2], J.B. Pettersen[1], G. Tranell[1]
[1]Norwegian University of Science and Technology, Norway
[2]Mintek, South Africa

Life cycle assessment (LCA) is a well-established methodology for evaluating environmental impacts, providing a holistic foundation for decision making and enabling comparison and assessment, whether by industry players, policy makers or researchers. However, to ensure the validity of these assessments, particularly for impact categories determined from heavy metals emissions in particulate matter and slag, significant improvements are needed in inventory determination to quantify the human toxicity and ecotoxicity of metal production.

Acquiring emissions data for heavy metals is often hindered by the fact that data is frequently proprietary within industry, measurements are limited to fixed conditions, and the number of measurements is small. This makes the data statistically questionable and limits its availability and reliability for research, and to support environmental policy.

This study investigates three key aspects to address this gap. First, it evaluates the environmental impacts of an industrial ferrochrome smelting complex using real-world operational data, which is the core of the analysis.

Delineated from this, the second aspect focuses on determining heavy metal air emissions; in which measured off-gas particulate matter analyses is substituted with thermodynamic modelled values. This approach offers an alternative to conventional methods relying on isokinetic testing, which is conducted under ideal, stable conditions, and often unavailable to researchers.

Furthermore, for slag, industry predominantly relies on static leaching tests to predict heavy metal release. These tests are limited because they fail to represent the true dynamic conditions of an environment, often leading to exaggerated inventory inputs for LCA and inaccurate impact assessment results. To provide a more realistic prediction for slag, the third aspect involves the development of a foundational numerical model using time-dependent modelling to predict long-term heavy metal leaching, which would be used to substitute the emissions values typically acquired via static leaching tests.

The value in investigating these methods of determining water and air emissions is that it creates a more robust, systematic and scientifically defendable framework for LCA, particularly in metal production in the absence of industrially measured data for these facets. Furthermore, these methods can be applied to different furnace conditions and operational parameters.

While the methods developed and studied provide a foundation for determining heavy metal emissions, they represent an initial step. Further verification through experimental studies is required to validate, refine, and confirm their accuracy and practical application in real-world scenarios.

Shana Joy Baumgartner

PhD Candidate
Norwegian University of Science and Technology (NTNU)

Shana Joy Baumgartner holds a Bachelor of Engineering Honours degree in Metallurgical Engineering from the University of Pretoria and a Master of Engineering degree in the same field from Stellenbosch University. With over 12 years of industrial experience, she has held various operational and technical roles within the copper and ferrochrome industries.

Shana is currently pursuing her Doctor of Philosophy at NTNU. Her research focuses on the life cycle assessment of ferroalloys, with a particular emphasis on understanding slag emissions and developing predictive models for heavy metal emissions. In addition, she is investigating novel green and circular processes to produce silicon metal.

Analysis of carbon emission reduction opportunities in an integrated steel plant for environmental and business sustainability

M. Estabrooks, N. Aubry, M. Sukhram, I. Cameron, F. Liu
Hatch Ltd., Canada

The steel industry is a major contributor to global greenhouse gas emissions, with a large portion coming from the integrated blast furnace – basic oxygen furnace steel production route. Designated a hard-to-abate sector, the steel industry is examining a range of pathways to reduce carbon emissions to align with global sustainability initiatives. As the industry pursues sustainable steel production and reduced greenhouse gas emissions, several step changes will be required, covering all key areas of the integrated steel plant operations. These include raw material selection, utility operations, and technology upgrades in areas such as the coke plant, sinter plant, and blast furnaces.

This paper investigates carbon emission reduction opportunities that can be implemented in the integrated steel plant and compares them to a representative base case to highlight the degree of possible improvement. Specific emission reduction opportunities investigated include equipment and operational improvements such as increased pulverised coal injection, blast furnace burden distribution improvements, raw material changes, process monitoring and control improvements, and green energy production and use. The challenges associated with emission reduction and the corresponding reduction in on site power generation using available process gases is discussed with various methods to overcome these challenges. Financial sustainability is a critical aspect to maintaining the steel sector's competitiveness, in addition to carbon emission reduction and environmental sustainability. This paper analyses the operating cost impacts of the suggested emission reduction pathways and outlines some important cost constraints.

Megan Estabrooks

Process Engineering Trainee
Hatch Ltd.

Megan Estabrooks is a process engineering trainee with three years of experience working at Hatch Ltd. in Mississauga, Canada. Megan graduated from Western University's chemical engineering program and Ivey Business School's HBA program. Through working on Hatch's Pyrometallurgy team, Megan has worked on projects in both the ferrous and non-ferrous industry, ranging from concept studies to basic engineering work. Megan has work experience with graphite purification and ferro-alloy electrolysis. Megan also has several project experiences working with integrated steel plants. Most recently, Megan has been working on studies investigating carbon emission alternatives in steel plants, considering the site wide emission impact as well as operating cost and capital expenditures. Megan has also co-authored a paper published in AIST's Iron and Steel Technology magazine investigating methanation as an emission reduction opportunity in the blast furnace.

Advances in graphite electrode manufacturing: Implications for electric arc furnace efficiency and sustainability

B. Yari
Hatch Ltd., Canada

Graphite electrodes are essential components in electric arc furnace (EAF) operations, significantly influencing process economics, energy efficiency, and sustainability. While EAFs are widely used in steelmaking and aluminium production, their applications extend to other metallurgical processes as well. This paper reviews the chronological improvements and recent innovations in graphite electrode manufacturing, including raw material selection, process technology, and mechanical design, and evaluates their impact on electrode performance and lifecycle. The review also explores the role of high-performance electrodes in optimising EAF operations, reducing electrode consumption, and minimising carbon emissions. Lifecycle assessments and recycling strategies are discussed to highlight environmental considerations. The paper concludes with recommendations for future research and the industrial adoption of advanced electrode technologies to improve competitiveness and sustainability in EAF-based processes, with particular emphasis on steelmaking and related metallurgical applications.

Bahman Yari

Hatch Ltd.

Bahman Yari is a process engineer at Hatch Ltd. in Mississauga, Canada, with specialized expertise in battery materials, high purity alumina, graphite, and pyrometallurgical process development. He has contributed to a range of industrial projects focused on the design and optimization of carbon-based materials used in high-temperature metallurgical systems, including graphite electrodes and coke feedstocks. Bahman's experience spans both rotary kilns and roller hearth kilns, where he has worked on process strategies to enhance thermal efficiency, material transformation, and product consistency. His work emphasizes the link between material properties and furnace performance, particularly in electric arc furnace (EAF) operations, where electrode quality and thermal behaviour are critical to energy efficiency and process stability. He is committed to advancing sustainable practices in pyrometallurgy through material innovation, lifecycle analysis, and operational excellence.

Dissolution of SiO_2 in SiO_2-CaO-Al_2O_3 slags

M. B. Folstad, M. Zhu, M. Tangstad
Norwegian University of Science and Technology, Norway

The dissolution rate of silica into different compositions of SiO_2-CaO-Al_2O_3 slags was studied at 1500°C and 1550°C under an inert atmosphere of argon. The results show that the dissolution process is controlled by mass transfer of SiO_2 in the slag. The experimental results were used to evaluate the dissolution rate, which was found to increase with increasing CaO/Al_2O_3 ratios as well as with increasing temperature. Boltzmann–Matano analysis was applied to obtain a profile-based effective chemical inter-diffusivity. The extracted inter-diffusivity coefficients decrease systematically with increasing SiO_2 content and fall in the range of ~10^{-12} – 10^{-13} m^2/s. These low values imply intrinsically slow diffusion-controlled SiO_2 enrichment, so that approaching equilibrium is unlikely within the residence time of descending materials in industrial furnaces.

Marit Buhaug Folstad

Postdoctoral
Norwegian University of Science and Technology

Dr Marit Buhaug Folstad is a researcher and metallurgist specializing in silicon and ferrosilicon production. With a PhD focusing on slag and quartz, Marit has developed a deeper understanding of the slags structure and behaviour, and the silica polymorphs, melting behaviour and disintegration during heating to elevated temperatures. In 2017 she completed a master's thesis that examined the effect of different silica polymorphs on the reaction between SiO2 and SiC, providing valuable insights into how raw material selection impact the production process.

Throughout the academic and professional career, Marit has contributed with conference presentations and papers, and peer-reviewed journal publications. The work has explored key challenges such as:

- Dissolution of CaO in SiO_2-CaO-Al_2O_3 slags
- Disintegration and melting behaviour of silica during heating to elevated temperatures
- Analyzes from industrial samples from several silicon and ferrosilicon plants providing valuable insights into the production process

Marit's research interests aim to continue to center on high-temperature process metallurgy. By combining experimental investigations with thermodynamic modelling, we aim to provide solutions that enhance efficiency and sustainability to optimize the furnace operation in silicon and ferrosilicon production.

Silicon production through aluminothermic reduction of solar photovoltaic glass

L. Meistad, L. Smemo, G. Tranell
Norwegian University of Science and Technology, Norway

Glass from solar panels typically becomes waste after they are decommissioned. In this paper, we explore producing a silicon alloy from this glass using aluminium as the reductant. For the aluminium source, we compared scrap Al with two fractions of dross, a byproduct of aluminium production containing alumina as well as metallic aluminium. As a proof of concept, we heated glass and scrap/dross to 1500°C for 60 minutes together with CaO as a flux in a graphite crucible. We characterised the resulting alloy and slag with electron probe microanalysis. Experiments consistently yielded alloys with a silicon content of >95wt%. Both dross fractions and the scrap produced similar metal phases, indicating that this process can effectively make use of recovered solar glass and lower grade aluminium streams to produce high grade silicon.

Linus Meistad

PhD Candidate
Norwegian University of Science and Technology

Master's degree in material science from the Norwegian University of Science and Technology with a thesis on valorization of fly ash. Currently doing a PhD about valorization of manganese sludge. Previous work has included pyrometallurgical experiments, hydrometallurgical experiments, and simulations in HSC and FactSage. Current research focus is utilization of resources and waste streams.

Quo Vadis – Refractory management in Pierce Smith converters?

D.M. Brazier
Refractory and Metallurgical Solutions (Pty) Ltd, South Africa

The Pierce Smith Converter (PSC) remains a cornerstone of copper smelting operations, yet its refractory systems face mounting challenges in the pursuit of efficiency, longevity, and cost-effectiveness. This presentation explores the evolving landscape of PSC refractory performance, emphasising the shift from traditional corrosion-centric assessments to a more nuanced understanding of thermal mechanical wear mechanisms. Drawing on field data, campaign analysis, and experimental insights, it highlights the critical role of operational practices—temperature control, slag chemistry, and tuyere management—in influencing refractory life.

As the industry confronts higher throughput demands and fluctuating commodity cycles, the question "Quo Vadis – Refractories?" invites a strategic reflection: Where must refractory technology go to meet tomorrow's metallurgical realities? The answer lies in tailored material selection, predictive maintenance strategies, and design innovations that address site-specific stressors. The presentation advocates for a data-driven, proactive approach to refractory management, moving beyond reactive repairs toward integrated solutions that enhance converter reliability and profitability. Ultimately, the future of PSC refractories will be shaped not only by material science but by the operational intelligence applied in their use. This talk provides a roadmap for navigating that future—one built on insight, innovation, and informed decision-making.

Freeze lining stability: From steady to changing slag chemistry through slag engineering

A. Malfliet[1], G. Butin[1], L. Scheunis[2], B. Blanpain[1]
[1]KU Leuven, Belgium
[2]Umicore, Shanghai, China

Freeze linings are self forming layers of solidified bath material that protect pyrometallurgical furnaces from aggressive process conditions and enable stable long term operation. Freeze lining research is strongly embedded in the broader concept of slag engineering, recognising slag composition as a key control parameter governing freeze lining formation, phase assemblage, thermo mechanical behaviour, and chemical stability. Rather than treating freeze linings as passive protective layers, our approach is to consider freeze linings as engineered, evolving materials whose performance can be tailored through deliberate control of slag chemistry and thermal conditions. This perspective provides a unifying framework linking laboratory experiments, microstructural analysis, and industrial process optimisation.

Traditionally, freeze lining behaviour is studied under steady state conditions, assuming constant slag chemistry and thermal boundary conditions. However, both primary smelting and recycling operations increasingly operate under non steady conditions. In primary smelting, the shift toward low grade and more complex mineral resources generate compositionally variable slags, thereby altering the slag properties and the process stability. In parallel, recycling streams impose feed variability due to the heterogeneity of the input material. Together, these trends drive smelting operations toward inherently non-steady chemical conditions. Understanding freeze lining stability as systems transition from steady to changing slag chemistry is therefore of growing industrial importance. Building on the knowledge obtained on steady-state conditions, a novel experimental approach has been elaborated to address freeze lining stability during transitions in slag chemistry. Using controlled laboratory scale finger test experiments, a freeze lining is first formed under steady slag conditions and subsequently exposed to a molten slag with a different composition. This methodology enables direct investigation of transient phenomena, including partial remelting, dissolution, phase transformation, and re crystallisation at the freeze lining–slag interface. Microstructural and chemical analyses demonstrate how the shift from steady to changing slag chemistry governs freeze lining integrity, revealing both destabilising mechanisms, such as fracture, thinning and drop in interface temperature, and stabilising effects through the formation of dense, high melting point crystalline layers.

Overall, our work advances freeze lining research beyond steady state assumptions and highlights slag engineering as a central tool for robust freeze lining design and operation in industrial smelting furnaces.

Ferroalloys furnace lining management – guideline for operators to extend furnace lifetime

C. Coetzee[1], S. Arjun[2], M. H. Erwee[3], S. Swanepoel[3], C. Briedenhann[1], R. Webb[1], J. van Rooyen[4]
[1]Intocast South Africa, South Africa
[2]Tru-ficiency, South Africa
[3]Samancor Chrome, South Africa
[4]OPM Industrial, South Africa

Due to the existing market downturn of commodities and cost pressures on ferroalloys producers, extending refractory lining lifetime, postponing complete relines and preventing furnace run-outs are major economic and safety drivers. Furnaces are run at maximum capacity until they reach the end of lifetime. Furnace relines are not only costly but having multiple furnaces offline results in less production and directly impacts profitability. In this competitive, cost-driven market, the role of lining monitoring and management is becoming increasingly important. Lining management requires a comprehensive understanding of furnace design criteria, engineering principles and thermal modelling (heat transfer and heat flux calculations) of a particular furnace. Lining monitoring is so much more than just thermocouple readings. There is a direct correlation between refractory wear, sidewall and hearth cooling, operational and metallurgical factors, tap-hole management, maintenance and original furnace design criteria. Thermocouples are damaged by lining and shell movement, refractory wear and being subject to proximity of metal and slag. On older furnaces especially the accuracy and validity of the thermocouple reading can be questionable. The aim of this paper is to review all on-site methods operators can use to monitor and improve furnace lining lifetime in combination with establishing a basic understanding of furnace engineering principles.

Colette Coetzee

Technical Sales Ferroalloys
Intocast South Africa

Colette Coetzee holds a BSc. (Industrial Chemistry) and MSc. (Metallurgy) from the University of Pretoria as well as MBA from Northwest University in South Africa. She has 24 years of experience in the metallurgical and refractory industries.

She started her career as a Senior Research Metallurgist at Billiton as well as Production Engineer at Metalloys. As Account Manager Africa and Middle East at GrafTech she spent time at smelters in South Africa, Korea, India, DRC, Europe, USA, Mexico and China, promoting freeze lining technology for platinum, ferrochrome, steel, ferromanganese, ferrosilicon, silicomanganese and titanium operators. At Tenova Pyromet she was involved with process, plant design and commissioning in South Africa, India and Russia.

At Intocast South Africa she is involved with furnace lining design, materials supply, demolition, and installation as well as technical expertise to ferroalloys suppliers globally. She is a keen supporter of skills and knowledge transfer - Transferring skills, knowledge and experience to the next generation is the most important legacy we can leave behind. What we decide to do today will determine where we will be tomorrow!

Development of thermodynamic database for V oxide containing slag systems and application to pyrometallurgical process

J. Nam, I.-H. Jung
Seoul National University, South Korea

An accurate thermodynamic database for the CaO-MgO-Al_2O_3-SiO_2-FeO-Fe_2O_3-VO_x system was developed based on the critical evaluation of available literature data and new phase diagram experiments. In particular, the multiple oxidation states of V (V^{3+}, V^{4+} and V^{5+}) in the oxide system were thoroughly taken into account in the modelling to cover the phase equilibria under both oxidising and reducing conditions. In this study, the key phase diagram experiments and thermodynamic modelling results for several important ternary systems will be covered, and the applications of the thermodynamic database for the Fe-V production process will be presented.

Advances in vanadium processing

G. Mulder, W. Steinberg
Hatch, South Africa

The presentation elaborates on the advances in vanadium processing to increase productivity, reduce operating costs and enhance process stability. Additionally, it is known that environmental compliance is becoming more stringent with more focus placed on energy utilisation and integration.

Key themes of the co-production process are explored and include mining at scale to reduce overall ore costs, maximising pre-reduction to reduce the reliance on electricity, improving the SER of the ESF, introduction of viable methods for the reuse of available thermal or chemical energy and the develop viable ways to reduce the environmental impact of the TiO2 slag. External (non-technical) factors include the impact of reduced electricity costs, improved logistical capability to enable lowest transport costs, ensure favorable vanadium trade conditions and favorable mining environment for stable low-cost operation.

This presentation starts to identify, on a high-level, what it will take to reinvigorate the VTM processing flowsheet, the possible technical opportunities to improve profitability and environmental aspects for the successful production of vanadium and steel in South Africa.

Gisella Mulder

Senior Process Engineer,
Industrial Clean Technologies AIM Regional Lead
Hatch

Gisella is a Process Engineer in the Hatch Industrial Clean Technology Business Practice. She completed her B.Compt degree in 2017 after also dabbling in teaching and journalism early in her career. Gisella is now leading the Hatch Industrial Clean Technology Group in the Africa, India, and Middle East region. Gisella and her team is committed to creating positive change by safely, sustainably and innovatively designing and implementing practical gas handling solutions that is geared towards a greener economy. Additionally, Gisella has been involved in many pyrometallurgical projects and has expertise as both a Process and Project Engineer on various projects within different commodities. Gisella's project suite spans from Scoping Study to Execution Projects and also include operational support and debottlenecking engagements.

Design of the containment system of an electric open bath DRI smelting furnace for green iron production

S.C. Louw, G. Lötter, P. Conradie, G. Farmer
Metix, SMS Group, South Africa

The overall integrity of the containment system is essential to achieving both safety and sustained throughput performance in smelting furnace design and operation. This integrity is supported by a combination of factors that contribute to the long-term reliability of the system. Key considerations include the chemical compatibility of the refractory material with the metal and slag, cooling element design, furnace binding system design, and the operational strategy of the furnace. In pursuit of a robust and sustainable solution, Metix launched a focused technology development programme to design high-capacity rectangular six-in-line electric open-bath smelting furnaces for processing highly metallised Direct Reduced Iron (DRI) to produce carburised hot metal (2–4.3 wt-% C).

As part of the technology development programme, the Technology Readiness Level (TRL) stage-gate approach was adopted. The TRL levels considered during the development programme were:

1. TRL 0:
    a. Idea generation and evaluation.
    b. Fundamental thermodynamic evaluation of refractory material compatibility with metal, slag, and gas product phases.
2. TRL 1 to 3:
    a. Bench scale refractory-slag and refractory-metal test campaigns.
    b. 200kW Pilot scale test campaign.
    c. Systematic excavation and technical evaluation of pilot unit crucible.
3. TRL 4 to 7:
    a. Design and development of pilot scale containment system.
    b. Pilot scale demonstration of containment system.
    c. Systematic excavation and technical evaluation of pilot unit crucible.
    d. Basic and detailed design of industrial scaled units.

The TRL approach led to clear and definitive conclusions, collaboratively providing a containment system design proven from fundamental principles, demonstrated on pilot scale, and implemented on an industrial application.

This paper outlines the critical design and operational elements addressed during the de-risking roadmap and details the TRL process followed through to the completion of the detailed engineering phase, highlighting how these foundations support sustainable furnace performance in a competitive industrial landscape.

Extension of ferrochrome furnace lifetime – Technical dig-outs to repair furnace hearths and clovers leaving sidewall brickwork refractories intact

C. Coetzee[1], P. Pienaar[1], M.H. Erwee[2], S. Swanepoel[2], S. Arjun[3]
[1]Intocast South Africa, South Africa
[2]Samancor Chrome, South Africa
[3]Tru-ficiency, South Africa

South Africa's ferrochrome producers are facing significant cost pressures with these factors leading to reduced production, smelter closures and a shift towards chrome ore exports instead of smelting ferrochrome. Key cost pressures include high electricity cost, global price competition, rising ore and reductant costs, logistics costs and ageing infrastructure. In this cut-throat environment the aim for survival is preserving cash flow and cost-saving initiatives. Ferrochrome producers do not have the luxury to spend millions on spare linings for every furnace in their fleet. Producers are increasingly looking at new innovative types of repairs to extend furnace and refractory lifetimes. A novel approach to extend freeze lining lifetime without reline has been developed by South African producers and Intocast South Africa. This approach includes fast high-level demolition to keep refractory sidewalls intact to get to problem areas at the clovers, tap- holes and furnace hearths.

Colette Coetzee

Technical Sales Ferroalloys
Intocast South Africa

Colette Coetzee holds a BSc. (Industrial Chemistry) and MSc. (Metallurgy) from the University of Pretoria as well as MBA from Northwest University in South Africa. She has 24 years of experience in the metallurgical and refractory industries.

She started her career as a Senior Research Metallurgist at Billiton as well as Production Engineer at Metalloys. As Account Manager Africa and Middle East at GrafTech she spent time at smelters in South Africa, Korea, India, DRC, Europe, USA, Mexico and China, promoting freeze lining technology for platinum, ferrochrome, steel, ferromanganese, ferrosilicon, silicomanganese and titanium operators. At Tenova Pyromet she was involved with process, plant design and commissioning in South Africa, India and Russia.

At Intocast South Africa she is involved with furnace lining design, materials supply, demolition, and installation as well as technical expertise to ferroalloys suppliers globally. She is a keen supporter of skills and knowledge transfer - Transferring skills, knowledge and experience to the next generation is the most important legacy we can leave behind. What we decide to do today will determine where we will be tomorrow!

Tenova's composite copper-graphite cooler design for enhanced PGM furnace performance

G. de Villiers, H. Joubert
Tenova Pyromet, South Africa

Tenova's innovative composite copper-graphite cooler design addresses the unique challenge of sulfidation corrosion encountered in platinum group metal (PGM) smelting furnaces in South Africa. The design features graphite sheathing over all copper surfaces vulnerable to labile sulfur, effectively inhibiting the onset of sulfidation—a corrosion mechanism particularly prevalent in local PGM operations.

Central to the cooler's safe operation is the incorporation of shallow cooling water channels within the copper elements, significantly mitigating the risk of water leaks into the furnace environment. Extensive test work preceded implementation, rigorously validating both constructability and cooling performance under extreme service conditions.

Following successful deployment in an industrial PGM furnace, operating data and performance metrics confirmed reliable functionality and robust cooling efficiency. After 29 months of continuous operation, coolers above the matte tap-holes were extracted for comprehensive evaluation, including visual and dimensional inspection, full dismantling to assess sulfidation corrosion, and analysis of the copper-graphite bond integrity.

Laboratory investigations encompassed conductivity measurements of the copper, elemental analysis of the graphite to detect any compositional shifts, and assessment of the graphite's cold crushing strength, bulk density, and apparent porosity. Results demonstrated sustained material integrity and performance, validating the cooler's long-term reliability.

Insights from the post-operational evaluation informed subsequent design refinements, further enhancing constructability and operational safety. This paper presents the design philosophy, test methodologies, performance results, and lessons learned from the extended service of Tenova's composite copper-graphite coolers, offering a robust solution to the persistent challenge of sulfidation in PGM smelting applications.

Gerrit de Villiers

Senior Engineer
Tenova Pyromet

Gerrit de Villiers is a Mechanical Engineer with over twenty-five years of experience in the steel and pyrometallurgy industry. He began his career at Voest Apline South Africa working in the South African steel industry.

In 2008, Gerrit joined Tenova Pyromet as a Project Engineer, where he has been actively involved in the design and delivery of equipment for large-scale furnace installations. His work includes contributions to greenfield furnace projects, furnace rebuilds and brownfield upgrades, providing him with valuable exposure to design, site execution and operational challenges. He is currently a Senior Engineer focussing on the development and implementation of furnace equipment and new technologies within the Base Metals field.

Impact of feed mixture control on arc behaviour in DC arc furnace smelting of chromite – A modelling study

Q.G. Reynolds[1,2], M.W. Erwee[3], S. Swanepoel[3], R. Fourie[3]
[1]Mintek, South Africa
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[3]Samancor Chrome Ltd, South Africa

Unexpected excursions in electrode hoist position are occasionally observed on DC arc furnace plants producing ferrochromium (FeCr), and are not readily explained by changes in electrical power supply or known process disturbances. One possible mechanism for this is variations in feed reductant balance altering the freeboard gas composition and hence the thermophysical properties of the arc plasma, changing the arc's effective electrical resistance. This hypothesis is investigated using an integrated computational modelling workflow comprising thermochemical equilibrium simulations in FactSage, plasma property calculations using the open-source minplascalc tool, and magnetohydrodynamic arc simulations using the open-source plasmaArc solver. Three reductant balance conditions were examined across a range of effective slag temperatures. Results show that while the reductant balance does influence freeboard gas composition and certain plasma properties (particularly electrical conductivity and radiation emission coefficient when lower slag temperatures are considered), these two effects act in opposing directions and largely cancel one another. Arc voltages and resistances are consequently not significantly different between reductant conditions. It is concluded that variations in feed reductant balance are unlikely to be the primary cause of the observed hoist excursion events via this mechanism, and directions for future investigation are proposed.

The full paper will be published in the SAIMM Journal

Dr Quinn Reynolds

Technical Specialist
Mintek

Quinn holds degrees in Engineering and Applied Mathematics. He has worked in the Pyrometallurgy Division at Mintek for over 25 years. Mintek is a state-owned research institute serving the extensive mineral and metallurgical processing sector in South Africa. Quinn is also an extraordinary professor in the department of Chemical Engineering at Stellenbosch University. His expertise includes mathematical and computational modelling of complex coupled phenomena in high temperature processes, and in particular the application of highperformance computing and open source software platforms to pyrometallurgy. His current areas of research include magnetohydrodynamic modelling of electric arcs, multiphysics fluid flow problems in furnace tapping and phase separation, combustion modelling for metallurgical processing, and reduced order modelling for digital twin applications.

Reduced order model for isothermal pre-reduction of chromite pellets with hydrogen

M. Khama[1], Q.G. Reynolds[1,2], B.S Xakalashe[1]

[1]Mintek, South Africa
[2]University of Stellenbosch, South Africa

Pre-reducing chromite with hydrogen offers significant benefits, including reduced energy consumption in downstream smelting and lower CO_2 emissions. To leverage these advantages, it is essential to develop computational models that facilitate the design, optimisation, and control of the process. Full-scale models such as 3D Computational Fluid Dynamics models are often used to investigate the multi-scale flow physics in heterogeneous reactors. However, these models impose prohibitive computational expense in the modelling of heterogeneous reacting flow systems. The high computational expense prevents the use of high dimensional systems in real time control and online optimisation of reacting flow systems. In order to facilitate incorporation of predictive models in the heterogenous reacting flow systems control loop, computationally-efficient reduced order models are required. Owing to these requirements, a reduced order model for pre-reduction of chromite with hydrogen was developed with the view to rapidly predict the performance indicators for pre-reduction of chromite with hydrogen. The Thiele modulus method was used to develop the reduced order model, and the model results were compared to isothermal pre-reduction experimental results at a range of pre-reduction temperatures from 1200°C – 1400°C. The model predicts the degree of reduction, diffusion of gases through the product layer, unreacted core radius of the grain radius, and local and global conversion. The final conversion across all temperatures as predicted by the reduced order model deviates from the experimentally calculated conversion by a maximum relative error of 2.7% while the initial conversions differ significantly; reaching a maximum error of 65%.

Mopeli Khama

Senior engineer
Mintek

Mopeli Khama holds a PhD in chemical engineering from the University of Kwazulu Natal. His PhD work focused on the development of computationally efficient CFD-Hybrid models for heterogeneous systems. He has also worked on Population Balance modelling of bubble column reactors during his MSc studies at the University of Cape Town. His current research interests are in the Computational Fluid Dynamics model development and analysis of gas-solid pre-reduction processes with the view to aid design and optimization. These CFD models will help the de-carbonization initiatives in the metal production processes. In addition, his work focuses on development of reduced order models that will be used as soft sensors in the future steel making technologies.

Effect of pellet size on the reduction behaviour of chromite pellets using gaseous hydrogen as reducing agent

A.H. Wicaksono, T. Fabritius, T. Kokkonen, V-V. Visuri
University of Oulu, Finland

Conventional ferrochrome production in Finland relies on carbothermic reduction of chromite pellets in a submerged arc furnace. This process involves melting a step which diminishes the influence of pellet size on its reduction behaviour. However, it generates substantial carbon dioxide emissions which are incompatible with decarbonisation goals. Consequently, hydrogen has been studied as a reducing agent in metals production, including the ferrochrome industry. Unlike carbothermic reduction, the hydrogen reduction process proceeds in the solid state, which places gas diffusion and particle geometry as decisive factors in the mechanism. As chromite pellets are produced within a certain size distribution as opposed to an exact and uniform size, understanding the effect of pellet size on the reduction degree achievable is essential. In this paper, various diameters of chromite pellets were reduced with hydrogen at two temperatures (1200°C and 1400°C) for four hours. In addition, the reduction degree was calculated. Results show that smaller pellets achieve higher reduction degrees than larger pellets. At 1400°C, the smallest pellet reached a reduction degree of 68.6%, while the largest pellet achieved 53.0%. A similar trend is also shown in an experiment at 1200°C. The smallest pellet reached 42.6%, while the largest pellet achieved 37.3%. Kinetic modelling also confirmed that ash diffusion layer is the rate-limiting step in this gas-solid interaction, which explains the high reduction degree of the small pellets. Therefore, these findings highlight pellet size as a key parameter in hydrogen direct reduction. Optimising its size distribution could enhance the efficiency of future ferrochrome production.

Aris Hadyo Wicaksono

Doctoral Researcher
University of Oulu

Aris Hadyo Wicaksono is a Doctoral Researcher at the University of Oulu. His research area is in the reduction of chromite. He holds Master's degree from University of Oulu, Finland and Montanuniversität Leoben, Austria and obtained Bachelor's degree from Universitas Indonesia. In addition, he has gained 7 years of experience by working at the Krakatau Steel, an integrated iron and steelmaking company in Indonesia.

Testing of refractory materials: An overview of how it assists in assessing suitability of a material for the intended application

A. Shonhiwa
Cermalab CC, South Africa

The cost of refractory materials constitutes a significant fraction of any pyrometallurgical process. Using the right refractory materials comes with many advantages, including increased equipment durability and lifespan, improved energy efficiency, and enhanced safety. All these benefits translate into lower operating costs by reducing fuel consumption, minimising repairs, and decreasing downtime. Assessing the suitability of a refractory material for its intended application involves evaluating its chemical, mechanical, and thermal properties in relation to the proposed application. Key properties include its chemical and mineralogical composition, refractoriness, resistance to thermal shock, as well as its density, porosity, and dimensional stability under high temperatures. Proper selection of a refractory material depends on matching these properties to the operating conditions, such as temperature and chemical environment. This paper will give an overview of the testing services offered by Cermalab CC in as far as testing of refractory materials is concerned and how the test results can assist refractory users in selecting the right material for any application.

Dr Aron Shonhiwa

Business Development Manager (Refractories)
Cermalab CC

With an educational background in Chemistry and Geology University of Zimbabwe, M.Sc in Material Science (Refractories) University of Sheffield (United Kingdom) and PhD in Material Science, University of Witwatersrand. Has been involved in all aspects of materials characterisation and testing since 1991. Has hands on experience in X ray diffraction , Scanning electron microscope and physical testing. Started working at the Metallurgical department in Harare and has worked in various companies including Ceramic tile, cement and concrete manufacturing in South Africa. Currently Business development Manager at Cermalab CC responsible for refractories, cement and concrete and related materials.

Understanding the quality of refractories

M.B. Berger
Cermalab, South Africa

Refractories are used for demanding conditions and need to be sound, robust and capable. Users of refractories need to understand this family of materials better so as to ensure the quality of their applications. This paper presents and discusses technical data sheets and their quoted properties, including: type of refractory, chemical and mineralogical composition, refractoriness, maximum service temperature, density and porosity, strength at room and elevated temperatures, thermal expansion, permanent linear change, thermal shock resistance, forms of silica, thermal conductivity, slag resistance, hydration and hydration resistance.

Melville Bruce Berger

Director
Cermalab CC

• In 1974 I joined Clay Products in Bulawayo as Production Supervisor
• In 1980 I joined Ferrovorm as Ceramics Technologist
• In 1984 I joined CSIR MATTEK division as Ceramics Research Technologist
• In 2002 I was one of the founding members of Cermalab. Cermalab is an independent SANAS accredited ceramics, refractories and materials testing laboratory.

AWARDS:
1980 - SA Ceramic Society Book Prize for Best Ceramics Technology Student.
1988 - Honorary Award from Technikon Pretoria for academic excellence
• Married for 47 years with 2 adult children
• A retired long-distance runner with 2 100-miler and 12 Comrades medals.

Composition of refractory materials. An overview of bulk chemical analysis and phase analysis of refractory materials with reference to the Al_2O_3 – SiO_2 system

A. Shonhiwa
Cermalab CC, South Africa

Selection of a refractory material for a particular application is mainly done based on chemical composition. However, two or more materials with the same bulk chemical composition might end up exhibiting different refractory properties and are therefore recommended for different applications due to them existing as different polymorphs /crystal structures.

This paper gives a general overview of bulk chemical analysis (XRF & ICP) and phase analysis (XRD) of ceramic/ refractory materials with reference to the Al_2O_3-SiO_2 system and how these two techniques can used to complement each other in order to have a better understanding of the behaviour, application and phase transformation of refractory/ceramic materials.

Dr Aron Shonhiwa

Business Development Manager (Refractories)
Cermalab CC

With an educational background in Chemistry and Geology University of Zimbabwe, M.Sc in Material Science (Refractories) University of Sheffield (United Kingdom) and PhD in Material Science, University of Witwatersrand. Has been involved in all aspects of materials characterisation and testing since 1991. Has hands on experience in X ray diffraction , Scanning electron microscope and physical testing. Started working at the Metallurgical department in Harare and has worked in various companies including Ceramic tile, cement and concrete manufacturing in South Africa. Currently Business development Manager at Cermalab CC responsible for refractories, cement and concrete and related materials.

A novel cooling liquid for pyrometallurgical applications: Metix's solution and TRL validation

S. de Beer
Metix (Pty) Limited, South Africa

Addressing the critical safety risks of water-based furnace cooling, this invention presents a novel, intrinsically safe heat transfer fluid. The fluid was rigorously evaluated using Metix's comprehensive de-risking strategy, combining precise lab-scale testing with advanced computational fluid dynamics (CFD) modelling to analyse its thermal and fluid dynamic properties, as well as its behaviour in molten materials. This project successfully developed a commercially viable and safer alternative, marking a substantial step forward for industrial safety and heat transfer technology.

Stefan de Beer

Product Manager
Metix (Pty) Limited

Stefan de Beer is a ferroalloy industry professional with 18 years' experience across ferrochrome and ferrosilicon operations. He holds a B.Eng. in Chemical Engineering (Mineral Processing) from North-West University (2007). Stefan began his career at Xstrata's Lion Smelter in 2008 and subsequently gained hands-on operational expertise at Silicon Technologies, focusing on submerged arc furnace operation, the prereduction Premus process, fines liberation, tailings management and project execution. He played a key role in the commissioning and start-up integration of Lion Smelter Phase 2 Furnaces and later served as Works Manager overseeing plant operations and strategic initiatives. Currently Product Manager at Metix, Stefan manages product portfolios, leads de-risking strategies and supports development across multiple technology readiness levels (TRLs). His combined operational and process-development background equips him to contribute practical insights on furnace performance, commissioning best practices and TRL advancement. His operational and process-development background positions him to contribute practical insights on furnace performance, commissioning best practices and TRL advancement at the SAIMM Pyrometallurgy International Conference 2026.

ILTEC: Safe, water-free pyrometallurgical furnace cooling with ionic liquid

A. Filzwieser, E. Bantjes, C. Sagadin
Mettop GmbH, Austria

Steam and hydrogen explosions caused by water entering high-temperature zones remain one of the most severe safety risks in pyrometallurgy. When water contacts molten metal, extreme volumetric expansion and hydrogen formation can trigger violent reactions, limiting safe operating windows and constraining furnace design. A non-flammable, water-free cooling medium fundamentally changes these boundary conditions and enables new levels of operational safety.

The patented ILTEC technology employs a specially engineered ionic liquid that is entirely non-flammable and non-explosive upon contact with molten copper, steel or slag. Unlike conventional organic heat-transfer oils, which can ignite once their flash point is exceeded, the ionic liquid does not burn and does not sustain combustion. When introduced into a melt, it exhibits only minor degassing and a characteristic greenish flame, eliminating the risk of steam or hydrogen explosions observed with water. This safety profile opens cooling applications that were previously impossible or prohibited due to explosion hazards.

Industrial implementations already demonstrate the capability of the technology: sub-bath cooling elements in copper metallurgy, tap-hole cooling in slag-cleaning and smelting units, near-surface lance cooling for improved bath penetration, as well as controlled thermal management of hot-dip galvanising baths including Zn and Zn–Mg systems. The medium's high thermal stability and sufficient heat capacity enable reliable heat extraction, while built-in leak detection, redundant pump systems and nitrogen blanketing ensure robust operational safety.

By eliminating both the explosion risks of water and the flammability hazards of organic coolants, ILTEC represents a transformative step in furnace cooling. It allows safer, more efficient and more flexible process operation, setting a new standard for modern high-temperature metallurgical systems.

Esli Bantjes

Project Manager
METTOP GmbH

With a strong technical background and extensive hands-on industry experience, he has built a career dedicated to supporting and advancing the pyrometallurgical industry. After completing his studies in the field of electromechanics, he developed a deep understanding of electrical principles and industrial systems, which became the foundation for his professional path in high-temperature metallurgical applications.

Early in his career, he focused on the manufacturing and development of pyrometallurgical cooling components for the global smelting industry. Through years of practical involvement in complex industrial environments, he gained comprehensive expertise in cooling technologies, furnace operations, and the demanding requirements of modern metallurgical processes. His technical understanding, combined with a solution-oriented mindset, enabled him to contribute to reliable and efficient cooling solutions that support operational safety, process stability, and long-term equipment performance.

Over the course of his professional journey, he has accumulated more than 15 years of experience in the pyrometallurgical sector. During this time, he has worked closely with customers, engineering teams, and production specialists across a wide range of international projects. His experience spans from technical consulting and project coordination to customer support and the successful implementation of tailor-made cooling solutions for challenging industrial applications.

In May 2023, he joined the METTOP team, where he continues to contribute his expertise and industry knowledge in the role of Sales Manager and Project Manager for cooling elements. In this position, he combines technical know-how with strong project management and customer relationship skills, supporting clients from the initial project phase through to implementation and after-sales service.
His practical industry experience allows him to understand customer challenges in depth and to develop reliable, efficient, and sustainable solutions tailored to specific operational requirements.

As part of the METTOP team, he is actively involved in strengthening the company's position as a trusted partner for innovative pyrometallurgical technologies and cooling solutions. His dedication to quality, technical excellence, and customer satisfaction reflects the values that drive METTOP's approach to industrial innovation and long-term partnership.

With his combination of technical expertise, industry experience, and commitment to practical solutions, he brings valuable insight into the challenges and future developments of the pyrometallurgical industry. His contribution supports not only the successful realization of projects, but also the continuous advancement of technologies that improve operational performance, safety, and sustainability within the global smelting sector.

Fundamental principles of electric furnace start-ups: Theory, applications and case study

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[1]Hatch Ltd., Canada
[2]Sibanye-Stillwater Mining Company, USA

Start-up is a critical phase during any electric furnace project that requires careful planning as they are challenging and very different from normal operations. Ensuring a successful furnace start-up that maintains long-term furnace integrity requires a clear understanding and a strict adherence to fundamental start-up principles and philosophy.

This paper presents and discusses fundamental start-up principles for the various phases of a typical electric furnace start-up. A variety of topics are discussed for each phase:
- Start-up Preparation (management, commissioning, sacrificial instrumentation, initial charge, diverter chutes)
- Burner Preheat (freeboard target temperature and rise rates)
- Electric Preheat (refractory temperature rise rates and hearth brick joint gap closure)
- Slag Pool Formation (pool formation and growth)
- Feed Addition (feed matte/metal bearing materials to reach tapping levels)
- Ramp-up to Normal Operation (reach nameplate capacity).

These start-up principles can be applied to a variety of commodities (ferronickel, platinum group metals, etc.), furnace types (AC vs DC, circular vs rectangular) and start-up types (green hearth with pool formation via solid slag, green hearth with bath formation via molten slag charge, frozen heel reheats after sidewall rebuilds, etc.).

This paper discusses at a high level how fundamental start-up principles were adapted and applied in recent start-ups performed by Hatch to ensure successful start-ups. The paper also presents a detailed case study of the recent start-up of a platinum group metals electric furnace at Sibanye-Stillwater Metallurgical Complex in Montana, USA. Data from the start-up is presented and analysed and lessons learned are summarised.

Jordon Perry

Senior Process Engineer
Hatch

Jordon is a process engineer with over 10 years of pyrometallurgy experience with Hatch. He has dealt with a range of processes including copper, ferronickel, platinum group metals, magnesium, and ferrochrome. His experience primarily includes the start-up and operation of electric furnaces, as well as equipment design of smelters.

Jordon has been the Furnace Start-up Manager for several electric furnace start-ups throughout his tenure at Hatch. He was responsible for managing a multidisciplinary team of engineers to ensure that each start-up was completed on schedule while minimizing risks to furnace integrity.

Investigating pore structure development of biocarbon sources at high temperature

N. Palamutcu
Norwegian University of Science and Technology, Norway

Biocarbon derived from renewable biomass sources represents a promising carbonaceous reductant for advancing sustainable production in metallurgical industries. A comprehensive understanding of the physicochemical behaviour and structural evolution of biocarbon under industrially relevant conditions is crucial for its effective integration into metallurgical processes. To address this need, the paper examined the reactivity of various biocarbon types using a Macro TGA furnace operated at 1100°C under different gas atmospheres, namely pure argon, an argon–CO/CO_2 mixture, and a CO/CO_2 mixture. Structural and chemical transformations of the biocarbon samples were characterised through Brunauer–Emmett–Teller analysis, scanning electron microscopy, and computed tomography. Particular attention was given to surface modifications and pore volume evolution. The results were interpreted in comparison with those obtained from fossil coke, which was employed as a reference carbon source.

Nuri Palamutcu

PhD. Candidate
Norwegian University of Science and Technology

I was born in Turkey, and I studied my bachelor and master's degrees in Istanbul. I completed a B.Sc. in Metallurgical and Materials Engineering at Yildiz Technical University. My research topic for graduating thesis was Graphene-based Additives for Gel Electrolytes of VRLA Batteries. After graduating from my bachelor's degree, I completed a M.Sc. in Material Engineering at Istanbul Technical University. My research area was alloying new kinds of aluminum alloys and my thesis topic was Effects of Niobium Addition on A206 Aluminum-Copper Alloys on Mechanical, Structural and Physical Properties. Me and my colleagues published an article from that research called Comparison of Tensile Properties of Nb Grain Refined A206 Alloy by Gravity and Tilt Casting. Before I graduated from my master's degree, I started to work as a special processes production engineer in an aviation and defense company called Gur Metal Investment Casting. I was responsible for the processes after casting such are welding, mechanical and chemical processes. My responsibilities were ensuring production of parts and removing defects on time and with necessary customer quality requirements. After the company has been sold to its largest shareholder, I started to do the same job duties for another company called Tusas Engine Industry which belongs to Turkish Defense Industry. After duration of one year of work in this company, I moved to Trondheim / Norway and started to work as a PhD. Candidate in Department of Materials Science and Technology at Norwegian University of Science and Technology. My research area is investigating the slag reactivities between slag and different biocarbon sources during manganese production.

PGM furnace hearth growth: A thermal perspective for operators

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[1]Valterra Platinum, South Africa
[2]University of Pretoria, South Africa
[3]Ex-Mente Technologies, South Africa

Continuous hearth growth remains a persistent risk in platinum group metal (PGM) six-in-line furnaces, with direct implications for shortened refractory campaigns, unplanned shutdowns, and increased likelihood of loss of containment. This paper investigates the thermal mechanisms underlying continuous growth by linking cooling efficiency, bottom-plate trip protection, and solidus-isotherm movement within the hearth refractory. Finite-element thermal simulations, supported by plant thermocouple data, demonstrate that compromised bottom cooling—either total loss of forced airflow or partial deterioration across the furnace width—drives irreversible downward migration of the 650°C solidus isotherm into the lower hearth refractory. The 650°C solidus temperature corresponds to the approximate solidification temperature of Fe-S-Ni-Cu-Co matte relevant to PGM smelting operations. In contrast, high matte-temperature cycles show minimal influence on solidus position due to the hearth's strong thermal inertia. Compromised cooling scenarios produce a calculated 60°C increase in refractory operating temperature and significant isotherm bowing, reinforcing the need for hearth cooling-system monitoring and robust trip protection. The solidus isotherm position defines the maximum depth to which liquid matte can remain mobile within the refractory; deeper isotherm migration therefore creates the thermal precondition for matte infiltration into the lower hearth. Recommendations for operators include improved instrumentation of hearth cooling efficiency, robust trip protection at 250°C, and proactive airflow integrity management. The findings present a thermally grounded mechanism for understanding continuous hearth growth, with coupled thermomechanical analysis identified as the logical extension.

Simba Kambewa

Section Manager Production
Valterra Platinum

I am a process engineer and metallurgical professional with over a decade of experience in smelting operations, process optimisation, and furnace integrity management within the platinum group metals (PGM) industry. My career has developed at the intersection of technical problem-solving and operational leadership, where I focus on achieving safe, reliable, and cost-effective performance in high-risk metallurgical processes.

I currently serve as Plant Manager for the Slag Cleaning Furnace (SCF) and matte granulation section at Valterra Platinum. In this role, I am accountable for delivering production targets while ensuring disciplined safety practices and stable furnace operations. I place a strong emphasis on structured management routines, team engagement, and proactive risk control, which has enabled me to drive both performance improvements and a culture of accountability.

Earlier in my career, I managed the safe retrenchment and transition to care-and-maintenance of a smelter operation. This was a complex assignment requiring sensitive leadership, rigorous cost control, and operational discipline. I successfully balanced the needs of employees, contractors, and stakeholders while ensuring safe decommissioning and continuity in reporting and governance structures.

My technical expertise extends to high-temperature modelling and furnace performance improvement. I am currently pursuing a Master's degree on continuous hearth growth in PGM furnaces, using finite element analysis (FlexPDE) to study thermal behaviour during start-up and steady-state conditions. This research focuses on the location of the matte solidus isotherm and its implications for furnace stability and integrity – insights that are critical for extending furnace life and reducing operational risk.

Beyond furnace modelling, I have also contributed to drying technology improvements, where I developed a roadmap to address underperformance in throughput and reliability. I have been actively involved in strengthening tapping safety, streamlining and resourcing initiatives for the annual Tapping Conference to ensure industry-wide impact and practical follow-through.

I hold a degree in Chemical Engineering and an Honors in Metallurgical Engineering and continue to broaden my knowledge through postgraduate study and professional engagement. I am particularly interested in the link between plant-level decisions and broader corporate and financial strategy in mining, as I see this integration as essential for sustainable value creation in the sector.

Through my work, I aim to combine technical depth, leadership, and strategic thinking to address challenges facing smelting operations. My commitment to safe, innovative, and efficient practice continues to guide my contributions to Valterra Platinum and to the wider metallurgical community through platforms such as SAIMM.

ECO Tab® - A new alumina aggregate for steel ladle lining

D. van Garsel, S. Klaus, A. Buhr, H.-L. Groß, D. Schmidtmeier, W. Zwijnenburg, J. Dutton
Almatis GmbH, Germany

ECO-TAB® is a new alumina refractory aggregate with lower density when compared to the globally produced Tabular Alumina T60/T64 (3.3 vs. 3.55 g/cm³). The business case for the development of this new aggregate is based on its application in a steel ladle wear lining. Two factors are relevant here. The heat capacity and the thermal conductivity of the wear lining material are important for reducing the thermal losses of steel into the refractory lining during the thermal cycling of the ladle whilst in use. With lower heat capacity and thermal conductivity of the lining, the heat losses while the ladle is empty can be reduced and accordingly the heat losses from the steel to the refractory lining later. In addition, a lower density and weight of the refractory lining enables lower materials demand and higher tapping weight of steel into the ladle when the maximum crane weight in the steel works becomes the limiting factor during the ladle campaign. Firstly, the volume is the limiting factor but with increasing refractory wear, the crane weight then becomes the new limiting factor. ECO-TAB® contributes to energy saving, capacity improvement, and reduced material consumption through lower weight of the refractory lining. The paper discusses material properties and application tests, as well as experiences with ECO-TAB® used in steel ladle refractory linings at European steel plants.

Doris van Garsel

Product line manager & Regional account manager
Almatis GmbH, Germany

After receiving a Master's degree in Materials Science Engineering in 1993 at the University of Clausthal, Germany, Doris joined Alcoa Industrial Chemicals, a global producer of synthetic alumina-based raw materials. The company changed in 2005 to Almatis and she still works for them today.

Work life at Almatis included various positions, starting with product development for cements, then European technical customer support, SAP introduction, to now working as global product manager for Almatis' calcium aluminate cements and as regional sales manager, a position which includes the South African market.

She is living in Frankfurt, Germany, is married and has two grown up daughters.

Inhibition of hexavalent chromium in refractory castables: The role of Elkem silica

H. Liu[1], A. Zhou[1], Q. Wen[1], I. Cameron[2,3], A. Garbers-Craig[3]

[1]Wuhan University of Science and Technology, China
[2]Elkem ASA, Norway
[3]University of Pretoria, Pretoria, South Africa

Chromium-containing refractory castables remain indispensable in severe service conditions—such as intense slag corrosion, thermal shock, and cyclic redox environments—across steelmaking, non-ferrous smelting, and waste-to-energy units, owing to their outstanding chemical stability and structural integrity. However, Cr_2O_3-based systems can undergo excessive oxidation in the presence of alkaline oxides and free alkali during heat treatment or high-temperature service, leading to the formation of hexavalent chromium (Cr(VI)). Cr(VI) is highly water-soluble and acutely toxic, thereby posing significant environmental and occupational health risks. Even with the incorporation of Si-containing products, calcium aluminate cement-bonded Cr-containing castables can still form substantial amounts of leachable Cr(VI) after service at 500–1100 °C [1]. Balancing performance retention with reliable mitigation of leachable Cr(VI) therefore remains a central refractory material design challenge.

This investigation introduced a novel no-cement binder system (SioxX®-Zero) together with Elkem Microsilica® 971U into the castable matrix formulation. The effects of these additives on the formation and leachability of Cr(VI) were systematically examined across different temperatures.

The results obtained for the fine-powder system indicate that at the lower temperature (500°C), neither SioxX®-Zero or Microsilica 971U effectively suppressed Cr(VI) formation; leaching tests detected measurable, albeit minor, amounts. Moreover, increasing the SioxX®-Zero dosage at 500°C tended to increase Cr(VI) formation, likely due to its specific binder characteristics and the associated local chemical environment. However, the amount of hexavalent chromium formed at this temperature appears limited, and extending the holding time did not lead to a further increase in Cr(VI) formation. At higher temperatures (900 and 1300°C), both Microsilica 971U and SioxX®-Zero were more reactive than Cr_2O_3 (eskolaite) toward CAC-related phases, promoting the formation of $Ca_2Al_2SiO_7$ (gehlenite) and $CaAl_2Si_2O_8$ (anorthite). These reactions correlated with a marked reduction of Cr(VI)-bearing species, lowering leachable Cr(VI) to trace levels. After high-temperature, and soaking for prolonged periods, storage at lower temperatures did not lead to the reappearance of Cr(VI) within the observation temperature window. A further set of leaching tests was conducted on the formulated refractory castables, following the European standard EN 14945:2005. The specimens treated at 500 °C exhibited leachable Cr(VI) contents of 717–975 mg/kg, while those treated at 900 °C showed substantially lower values of 25–58 mg/kg. At 1300 and 1500 °C, the leachable Cr(VI) content was limited to ≤5 mg/kg. Except for the specimens treated at 500 °C, the leaching values obtained at all other temperatures were below the EU landfill acceptance limit (70 mg/kg) for Cr in granular hazardous waste.

Overall, matrix composition containing SioxX®-Zero and Elkem Microsilica®971U—particularly the partial substitution of CAC with SioxX®-Zero—shows promise for enabling greener, regulation-compliant chromium-containing castables without sacrificing service-critical performance. The findings also delineate a low-temperature risk window (~500°C) in which Cr(VI) formation can occur, requiring careful control of SioxX®-Zero dosage. These insights provide practical guidance for optimising castable formulations and preparation strategies. (This work was supported by the Hubei Provincial Regional Innovation Program for International S&T Cooperation [Grant No. 2024EHA004], project title: Development of Chromium-Containing Refractory Materials for Waste-to-Energy.)

[1] Nath, M., Song, S., Xu, T., Wu, Y., Li, Y., 2019. Effective inhibition of Cr(VI) in the Al_2O_3-CaO-Cr_2O_3 refractory castables system through silica gel assisted in-situ secondary phase tuning. Journal of Cleaner Production 233, 1038–1046.

Hang Liu

Lecturer
Wuhan University of Science and Technology

Hang Liu is completing his Ph.D. in Earth Sciences (Mineralogy) at the University of Innsbruck. His doctoral research focuses on phase relations, crystal structures, and thermochemistry in the K_2O–CaO–SiO_2 system. She combines equilibrium experiments, in-situ high-temperature X-ray diffraction, calorimetry, and thermodynamic modeling to refine phase diagrams and elucidate reaction pathways relevant to applied mineralogy and refractory design. Prior to his doctorate, he earned a B.Eng. and M.Eng. in Metallurgical Engineering from Wuhan University of Science and Technology. His master's work investigated chromium-containing refractories (Al_2O_3–CaO–Cr_2O_3), mechanisms for Cr(VI) suppression, and environmentally safer lining materials, integrating inorganic synthesis, leaching kinetics, and DFT-supported thermodynamics. His technical toolkit spans powder/single-crystal XRD, SEM-EDS, and crystallographic analysis. He has presented his findings at international conferences and published in peer-review journals.

LCA as a tool for assessing the environmental impact of ferroalloy production – Past and future

Y. Ma, S.J. Baumgartner, J.B. Pettersen, G.M. Tranell
Norwegian University of Science and Technology, Norway

Life Cycle Assessment (LCA) is a standardised environmental management tool for quantifying the potential impacts of products, processes, or activities across their entire life cycle. It systematically evaluates environmental burdens from raw material extraction through production, use, and end-of-life management, thereby identifying stages or processes with the greatest contribution to environmental impacts. Ferroalloys are iron-based alloys containing substantial amounts of one or more alloying elements, such as manganese, chromium, or silicon. Their primary application lies in steelmaking, where they serve as alloying additions to improve mechanical properties. Industrial production of ferroalloys is predominantly conducted via carbothermic reduction of oxidic ores or concentrates, typically employing carbon in the form of coke or coal as the reducing agent. In the context of global efforts to achieve net-zero carbon dioxide emissions by 2050, decarbonisation of ferroalloy production has become a critical challenge. The substitution of fossil carbon with biocarbon, a carbon-neutral reductant, represents a promising approach to reducing greenhouse gas emissions in metallurgical processes. Meanwhile, metallothermic reduction using silicon or aluminium as reductants which avoids direct carbon dioxide emissions offers another alternative production route. LCA has been employed to evaluate the environmental performance of these production routes. Despite the importance of the ferroalloy industry, only a limited number of LCA studies have been reported, some of which focus primarily on energy consumption and associated greenhouse gas emissions. This paper aims to synthesise and critically evaluate the existing LCA literatures on ferroalloy production, comparing methodological approaches, system boundaries, and impact categories. By highlighting current knowledge gaps and methodological limitations, the review provides insights into how LCA can serve as a multi-criteria decision-making tool for assessing trade-offs among environmental and economic indicators in ferroalloy production. The findings offer guidance for future LCA studies and underscore opportunities to enhance sustainability, resource efficiency, and emissions reduction in the ferroalloy industry.

Yan Ma
Researcher
Norwegian University of Science and Technology

PhD in Materials Science and Engineering and postdoctoral experience in industrial ecology. Research expertise includes process simulation, thermodynamic modelling, life cycle assessment, and pyrometallurgy, with proven ability to lead interdisciplinary projects.

Physicochemical phenomena occurring during pgm smelting: Microstructural evolution of the black top and its transition to a slag-matte dispersion

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In platinum group metal (PGM) smelting, material behaviour in the higher regions of the furnace strongly affects matte recoveries. Yet the concentrate layer ('black top') and its interaction with slag remain poorly understood. Its role in controlling how sulfides and gangue report to bulk slag has mostly been inferred empirically, leaving key mechanisms unresolved. This paper addresses this gap by experimentally reproducing black top buildup and examining its transition into molten slag.

A laboratory-scale smelting setup was developed to replicate industrial temperature gradients and dynamic concentrate melting. Bushveld Complex concentrate and primary smelter slag from the Northern Limb were processed in a magnesia–chromite crucible using an induction furnace and a graphite susceptor to supply heat. Concentrate was gradually added onto molten slag, ensuring heating was primarily via slag-concentrate heat transfer, consistent with industrial practice. After sufficient buildup, samples were naturally cooled and analysed using SEM–EDS and XRD to map material evolution across the black top and slag interface.

In the black top, low-temperature phenomena are dominated by sulfide decomposition and melting. Molten sulfides form spherical and globular particles and interact with gangue in diverse ways, ranging from attachment to single gangue grains to pools where sulfides spread across multiple particles in a matrix. Simultaneously, gangue minerals undergo dehydroxylation and liquid-state sintering. Sintering produces small pores that progressively merge into larger voids, which act as sites for sulfide collection, coalescence, and the development of more homogeneous matte-like compositions.

The interface between concentrate and slag was not a sharp boundary but a progression from sintered concentrate into molten slag. Initially, sulfide interaction is governed by shrinkage of the gangue matrix with limited drainage. As sintering advances and the liquid fraction of gangue increases, sulfides become larger, more spherical, and more homogeneous, indicating the onset of liquid-phase settling and coalescence. Within the reactive zone, large pores provide evidence of bubble formation in the slag. Molten sulfide interactions are prominent here, but no flotation was observed, and no correlation was found between sulfide morphology and bubble size or shape, suggesting bubble effects are subtle. The presence of unreacted powdered concentrate beneath the liquid surface further highlights the dynamic and partially unstable nature of this transition region.

This study provides the systematic characterisation of microstructural evolution and phase interactions within the black top, its transition into slag and attempts to directly emulate a primary smelter. The findings highlight the importance of early sintering, pore development, and sulfide coalescence in governing how phases report to the bulk slag. These insights form a foundation for predictive models of furnace behaviour and open pathways for improving PGM smelting efficiency and reducing matte losses.

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Mbongeni Bhebhe is a Master's student in Metallurgical Engineering whose research with Anglo American Platinum focuses on the sintering and smelting behaviour of PGM concentrates. His work involves experimental and microstructural investigations to better understand phase evolution, interface phenomena, and process efficiencies in primary smelting operations. On campus, he has contributed as a laboratory assistant, tutor and an assistant lecturer in the Department of Materials Science & Metallurgical Engineering at the University of Pretoria.

Coalescence of sulfides under simulated PGM smelter conditions

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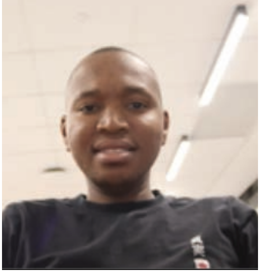
The coalescence and subsequent settling of sulfide matte droplets through the blacktop and slag layers in an electric furnace constitute the primary mechanism of matte separation and collection during platinum-group metal (PGM) concentrate smelting. This paper investigated the coalescence behaviour of sulfide matte droplets under laboratory-simulated PGM smelter conditions, focusing on the effects of total sulfide content, sulfide mineral composition, silicate mineral composition and the presence of chromite in concentrate feed blends used.

Two blends of Platreef, UG2 and Great Dyke-type concentrates, and a pure Great Dyke-type concentrate were isothermally heated at 1300°C, 1400°C and 1480°C for two hours in silica crucibles sealed in steel capsules under an argon atmosphere, followed by rapid quenching to preserve the high-temperature phase composition. After quenching, the crucibles were sectioned in half to prepare polished sections for microstructural, phase and chemical composition analyses.

Matte droplet size distributions were analysed at the top, middle, and bottom regions of the crucibles using the AZtec software feature analysis. Additional characterisation techniques included micro-XRF imaging, scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDS), and thermochemical modelling using FactSage 8.3. These methods provided comprehensive insights into how variations in sulfide content, sulfide composition, and chromite concentration influence matte coalescence.

SEM was used to analyse microstructures, while EDS analysis was used to determine phase compositions and interactions. Micro-XRF imaging was applied to map elemental distributions of Fe, Cu, Ni, Cr, S and Si to track sulfide coalescence and settling. FactSage 8.3 was used to predict the liquidus and solidus temperatures of the concentrate samples, the compositions of the liquid silicate phases, and their viscosities at the three working temperatures. Slag and matte physical properties (viscosity, surface tension and density) were estimated using published empirical models.



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Leni Maphalala; a dedicated Metallurgical Engineering graduate with a BEng and Honours degree from the University of Pretoria, majored in physical and extractive metallurgy with a strong passion for extractive processes. Currently pursuing a Master's in Metallurgical Engineering, focusing on the coalescence of sulfide matte droplets under platinum-group-metal (PGM) concentrate smelter conditions.

Alternative reductants for a slag cleaning furnace

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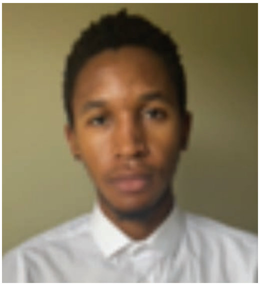
The pyrometallurgical processing of platinum group metal (PGM) concentrate involves smelting and converting. During the converting process, nickel, copper and cobalt are lost to the slag as oxides. These base metals can subsequently be recovered in a slag cleaning furnace (SCF) as a possible treatment route in which reductant (typically coke) is added to reduce these metal oxides, and a sulfur source (typically concentrate), which collects the base metals in a matte phase.

The use of coke is associated with the generation of greenhouse gas emissions. This paper therefore aimed to identify alternative reductants and optimal conditions that maximise base metal and matte recovery while minimising greenhouse gas emissions, thereby contributing to sustainable PGM processing. To align with circular economy principles and reduce reliance on fossil fuels, sustainable alternatives to coke were investigated – specifically, aluminium dross, silicon carbide bricks from spent refractories, and biochars derived from black wattle and macadamia nut shells.

The paper commenced with a detailed characterisation of the chemical and phase compositions of the SCF feed materials and the alternative reductants. Converter slag and concentrate were analysed using X-ray fluorescence (XRF), X-ray diffraction (XRD), and scanning electron microscopy (SEM), coupled with energy dispersive spectrometry (EDS). Coke and biochars underwent proximate analysis to quantify moisture, volatile matter, fixed carbon, and ash content. Silicon carbide bricks were characterised using XRF, XRD, and SEM-EDS to confirm composition and identify impurities. Aluminium dross was processed by melting to separate metallic aluminium from oxides; the aluminium was then leached in citric acid, the leachate evaporated, and the resulting powder analysed by XRF to determine impurities. FactSage thermochemical software was used to predict equilibrium phases.

Baseline tests, replicating industrial SCF operation with coke, were compared with tests using the alternative reductants – aluminium powder, silicon carbide powder, and biochar. The reductants were added in stoichiometric amounts based on the nickel oxide content in the converter slag. Reactants were blended, placed in magnesia crucibles, and sealed in argon-purged, welded steel capsules to prevent oxidation and sulfur loss from the charge. Experiments will be conducted at three temperatures (1380°C, 1430°C, and 1480°C) covering typical furnace operating ranges, with reductant additions varied by ±10% to assess the influence of temperature and dosage on reduction efficiency and matte formation. After establishing the behaviour of pure reductants, tests were performed using the actual alternative reductants from secondary sources to evaluate the impact of their impurities on the process.

Each test was held at the target temperature for two hours, followed by quenching to preserve high-temperature phases. Quenched samples were analysed using SEM-EDS to identify phase morphology and the elemental distribution of nickel, copper, cobalt and iron. High-voltage pulsed power fragmentation, using a Selfrag Lab S2.1 unit, was employed to separate matte and slag for quantitative analysis. Results were compared to FactSage predictions.



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Metallurgical Engineering graduate with a Bachelor's degree in Metallurgy and Materials from the University of the Witwatersrand (2023), where my final-year project on chromite pellet reducibility earned second place at the 2023 SAIMM YPC Student Colloquium. My industry experience includes vacation work at Sibanye Stillwater, where I worked on base metal recovery, smelting, and concentrator operations, and at Scaw Metals Group, where I worked on steelmaking and rolling mill processes.

Currently pursuing a Master's degree in Metallurgical Engineering at the University of Pretoria, researching alternative reductants for a slag cleaning furnace to enhance sustainability and process efficiency. I also serve as a postgraduate researcher, conducting experiments and analyzing data, and work as a tutor and lab demonstrator, supporting students in Materials Science and Minerals Processing modules.