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Book of Abstracts

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Waste Management & Environmental Compliance / 2

Influence of Granulation Media on the Reactivity of Electric Arc Furnace Slag as Supplementary Cementitious Materials

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The transition to hydrogen-based reduction processes will alter slag compositions and volumes in ore-based steelmaking, with potential consequences for the established industrial symbiosis between steel and cement sectors. Presently, ground granulated blast furnace slag is widely utilized as a supplementary cementitious material (SCM), replacing clinker and thereby lowering the carbon intensity of cement production. As blast furnaces (BFs) are expected to be locally replaced, alternative SCM sources from future ore-based steelmaking must be assessed. One such future route is the melting of hydrogen direct reduced iron in electric arc furnaces (EAFs), which generates slags that could be valorized as SCMs provided they are vitrified during granulation. Since granulation technologies involve different cooling rates and associated costs, the influence of granulation media on slag vitrification and reactivity is of particular interest. In this study, synthetic EAF and BF slags were granulated at laboratory scale using both water jets and air blasting. Continuous cooling transformation experiments using hot-stage confocal laser scanning microscopy showed that, relative to EAF slag, BF slag underwent greater supercooling prior to crystallization and exhibited lower growth rate. This was confirmed by the granulation experiments, where air granulation drastically reduced the amorphous fraction of EAF slag, while BF slag achieved nearly full vitrification with both media. The inherent reactivity, assessed by R3 isothermal calorimetry, reflected this difference: EAF slag reactivity was strongly dependent on granulation medium, whereas BF slag reactivity was less affected. Energy dispersive X-ray spectroscopy indicated similar glass compositions within the respective slag types, suggesting that the observed reactivity differences are linked primarily to vitrification and thermal history rather than chemistry. These findings underline the critical role of granulation media in pursuing EAF slag valorization as SCMs.

Speaker Country:

Sweden

Speaker Company/University:

Luleå University of Technology

Innovations in EAF Technology II / 3

Sulphur control as part of steelmaking transition. Challenge or opportunity

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Improving the quality of steel has been a matter of routine for metallurgical engineers and steelmaking companies in a demanding market for quality products. The traditional Electric Arc Furnace process has the lowest carbon emission compared to the integrated route, making it the best route

for green steel production. In addition, the industry is focused on ensuring that high-quality steel products can be produced smoothly, immediately after the transition.
One of the challenges is controlling sulfur residual in steel, which is critical for certain applications and has “secondary / additional”impact on overall steel cleanliness. Lesson learned from market with different feasibility studies, investigations and accumulated know how from long list of projects for different flat products, including thick and thin casting processes are summarized and reported in article.

Speaker Country:

Italy

Speaker Company/University:

Danieli & C.

Recent progress and new developments in CCS/CCU / 4

Production and Evaluation of a Carbon-Recycled Carburizing Agent to Promote the Melting of Direct Reduced Iron

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Global crude steel production has shown a steady increase in recent years, with approximately 70% produced via the blast furnace–basic oxygen furnace (BF–BOF) route and the remaining 30% by the electric arc furnace (EAF) process. The BF–BOF route consumes a large amount of fossil-based carbon materials, resulting in significant CO_2 emissions. Therefore, the transition from the BF–BOF process to the EAF process is considered a key pathway toward achieving carbon-neutral steelmaking. The EAF process produces molten iron by melting metallic scrap and direct reduced iron (DRI) using electric arc heat. Although it is a greener process with lower carbon consumption, a certain amount of carbon must still be added to lower the melting point of iron and to promote slag formation, which protects the furnace lining. Thus, even in EAF steelmaking, the use of carbon-neutral carbonaceous materials is essential.
Previous studies have explored the use of biomass as a carburizing agent. Biomass-derived carbon exhibited a dissolution rate of metallic iron comparable to that of anthracite, indicating its potential as a renewable carbon source. However, biomass supply is limited by availability, logistics, and cost, making it difficult to support large-scale steel production. To overcome this limitation, new sustainable carbon supply routes must be developed.
In this study, we focus on carbon capture and utilization (CCU) technology to recycle carbon emitted from steelmaking processes. We propose a novel approach in which the off-gas from the process is reformed using a metallic iron catalyst to recover solid carbon for reuse. The recovered carbon mainly consists of fibrous carbon several hundred nanometers in diameter and fine iron carbide particles. When this deposited carbon is briquetted with metallic iron particles and subsequently heated, it demonstrates excellent melting characteristics due to enhanced interfacial reactivity.
In situ observation experiments revealed that briquettes containing the deposited carbon melted at lower temperatures than those using conventional graphite as a carburizing agent. This result indicates that the deposited carbon promotes earlier melting and efficient heat transfer. The proposed CCU-based carbon recycling route offers a promising solution for reducing both carbon consumption and CO_2 emissions in EAF steelmaking. Overall, this study provides a new perspective on utilizing recovered carbon as a functional and sustainable carburizing material, contributing to the realization of truly carbon-neutral steel production.

Speaker Country:

Japan

Speaker Company/University:

Tohoku University

Energy Efficiency and Consumption Reduction / 5

iRecovery® and Heat Leap: Strategic Solutions for Efficiency and Low-Carbon Steel Production

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Electrical steelmaking is at the forefront of sustainable innovation, delivering major gains in energy and resource efficiency. Yet, even today, up to 30% of the energy input in EAF steel production escapes through off-gas emissions—representing lost value and increased environmental impact. Tenova's iRecovery® system transforms this challenge into an opportunity. By capturing the thermal energy in EAF waste gas, iRecovery® converts it into steam through an advanced evaporative cooling process. This steam can be reintegrated into the steelmaking cycle for internal use (e.g., vacuum degassing) or used to generate clean electrical power or for district heating.

Decarbonization with large EAFs requires a rapid reduction of off-gas temperature, which means absorbing a massive amount of energy very quickly. iRecovery® is the ideal solution because it achieves this goal without introducing moisture—avoiding an increase in gas volume and filter size—while simultaneously generating clean energy in the form of steam and electricity. It is the smartest way to manage primary energy in large-scale EAF operations.

But the energy recovery potential does not stop there. The concept of Heat Leap introduces an additional layer of efficiency: a high-performance heat pump that leverages the thermal power extracted from the EAF cooling circuit and combines it with the electrical input of the pump to deliver extra heat to district heating networks. This approach transforms residual energy into a valuable resource for urban infrastructure, reducing fossil fuel dependency and supporting circular energy models. By integrating Heat Leap with iRecovery®, steel plants can not only minimize energy waste but also become active contributors to sustainable city heating systems—creating a synergy between industrial processes and community energy needs.

The result: reduced energy waste, lower costs, and a greener steel production process that extends its benefits beyond the plant boundaries. iRecovery® and Heat Leap systems together represent a strategic enabler for decarbonization, efficiency, and competitiveness in modern steelmaking. This combined approach positions steel plants as key players in the global transition toward low-carbon economies, reinforcing their role in shaping a sustainable industrial future.

Speaker Country:

Italy

Speaker Company/University:

Tenova

Successful implementation of electric steelmaking technologies & Best practices / 6

Nozzle, skids and demisters have big influences on cleaning efficiency in off gas systems

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In order to comply with the stricter environmental regulations, efficient cleaning of the process and waste gases is crucial. In this context, even small, cost-negligible components such as nozzles and separators play an important role, as they have a significant influence on trouble-free, low-maintenance production and environmental regulations.
Lechler is a well-known manufacturer of nozzles and spray technology for various applications. The product range includes a variety of nozzles.
EAF have batch operations with frequent heating and cooling cycles. This rapidly varying heat load requires that droplet sizes and water flow rate respond maintain the desired temperature without causing any wetting and precise distribution of liquids in gases or aerosols.
In order to be able to select nozzles for the individual metallurgical processes, a wide range of criteria must be taken into account, which requires appropriate metallurgical process knowledge. The following things have to be considered for the nozzle selection: Energy saving and efficiency, droplet size distribution, efficiency, application-specific design and adapted control technology are decisive. On the other hand, other criteria are decisive for separation: emission reduction, improvement of air quality, recycling of process fluids and thus an increase in process efficiency. This combined knowledge makes Lechler a unique partner.
This paper highlights a case where Lechler spray technology played a crucial role in solving mill's persistent off gas cleaning issue.

Speaker Country:

Germany

Speaker Company/University:

Lechler GmbH

Energy Efficiency and Consumption Reduction / **7**

Multi-Stage Waste-Heat Recovery and Furnace Optimization in Seamless Pipe Production: A Case Study at Atieh Partak Pipe Industries

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Enhancing thermal efficiency and reducing operating costs are critical objectives in seamless pipe production, particularly in processes where billet preheating constitutes a major portion of total energy demand. In rotary hearth furnaces operating at billet temperatures near 1280 °C, a significant fraction of the fuel input is released as high-enthalpy flue gases, representing a valuable but underutilized source of recoverable energy. This study investigates the technical and economic feasibility of converting this waste heat into electrical power through an integrated Heat Recovery Steam Generator (HRSG) and Organic Rankine Cycle (ORC), while also examining furnace-level process optimization strategies. At Atieh Partak Pipe Industries, a strategic reduction in annual production capacity—from 400,000 to 150,000 t/year—prompted a preliminary engineering assessment to evaluate the elimination of the billet preheating furnace and the exclusive operation of the rotary hearth furnace as the primary heating unit. A comprehensive case study was subsequently conducted to quantify the recoverable thermal energy in the furnace exhaust and to assess its potential for power generation.
The methodology incorporates field measurements and energy–exergy analyses to characterize the exhaust temperature profile, mass flow rate, and gas composition. Three waste-heat recovery configurations were modeled: a high-temperature HRSG coupled with a small steam turbine, a dual-stage

HRSG–ORC system, and a ceramic recuperator integrated with a low-temperature ORC. Results indicate that, depending on operating conditions, several hundred kilowatts of electrical power can be generated. Overall, the proposed configurations are shown to be technically feasible and economically advantageous for the plant.

Speaker Country:

Iran

Speaker Company/University:

Atieh Partak Pipe Industries

AI and Machine Learning in Process Optimization II / 8

AI Assisted Thermal Modelling for Advanced Furnace Control and Process Optimization

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John Cockerill is developing AI-assisted enhancements to its physics-based furnace control models to improve process efficiency and stability in steelmaking. Building on the Line Thermal Optimization Process (LTOP) experience, this work explores how artificial intelligence can refine transient anticipation, heat transfer estimation, and adaptive response under changing operating conditions. The hybrid approach combines physical modelling with data-driven learning to reduce temperature overshoots and improve overall energy efficiency. The presentation will discuss the concept, preliminary results, and perspectives for integrating AI into model-based control to support higher performance and sustainability in future steel production lines.

Speaker Country:

Belgium

Speaker Company/University:

John Cockerill SA

New and emergent ironmaking Technologies II / 9

Volteron™: Scalable Electrochemical Ironmaking for Carbon-Free Steel Production

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With growing regulatory pressure and the need to achieve net-zero targets, new technologies for 'low carbon'steelmaking are being urgently explored. Volteron™, developed by the John Cockerill Group and ArcelorMittal Group, introduces a novel electrochemical ironmaking route based on low-temperature electrowinning of iron oxide. The technology eliminates direct CO_2 emissions and leverages renewable electricity to produce high-purity iron plates ready for downstream use in electric arc furnaces (EAFs).
This paper presents the scientific and engineering principles of the Volteron™ process, covering its ore preparation, electrolytic cell architecture, and product handling. It describes the pilot plant commissioned in April 2025 and outlines the technology's industrial roadmap, which is built around modular capacity scaling. Comparative analysis with hydrogen-based direct reduction (H_2-DRI) technologies is provided to highlight Volteron's advantages in terms of emissions, energy efficiency, scalability, and time-to-market.
Supported by a legacy of electrowinning technologies from the copper and zinc industries, Volteron™ offers a reliable and adaptable solution for decarbonizing steelmaking. With a demonstrated energy demand <3.75MWh/t and zero CO_2 emissions under renewable operation, this process could account for up to 14% of global steel production by 2050, according to IEA projections. The findings confirm Volteron's potential as a cornerstone of a sustainable metallurgical future and and a facilitator of the EAF decarbonisation.

Speaker Country:

Belgium

Speaker Company/University:

John Cockerill SA

Automation and Digitalization in Electric Steelmaking I / 10

Innovation in weighing technologies meet growing melt shop operation requirements

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Reliable, precise, and maintenance-friendly weighing systems have always been essential for safe and efficient production in the harsh environment of steel melt shops. Today, modern technologies empower us to equip key production assets with weighing systems that are both robust and highly accurate. This enables steel producers to meet the growing demands for safety, process control and optimization through solutions that are simpler and more dependable than ever before.

In this session of the EEC 2026 I like to present some of those proven modern melt shop and scrapyard weighing technologies:

Digitization of each loadcell signal close to its installation place

Digital loadcell signals enable precise recording, monitoring and supervision of both static and dynamic loads at each individual load point in real time. This capability allows for the early detection of local overloads and the easy localisation of damaged loadcells.

Online measurement of the loadcell temperature

Many heavy-duty loadcells used in liquid steel weighing applications are now equipped with integrated PT100 temperature sensors. They provide real-time temperature data to the PLC, helping to prevent loadcell damage caused by overheating.

Scrap loading with overload protection

Former designer generations separated scrap loading from weighing to protect the sensitive loadcells from huge dynamic loads. Nowadays this split of functions is no longer needed, as modern loadcells contain overload protections: loading and weighing can take place in the same process.

WLAN data transmission between mobile assets and the control room

All mobile melt shop assets - such as ladle transfer cars, ladle cranes, continuous casting machines, and tundish cars - require flexible and reliable data connections. Modern WLAN-based radio transmission solutions have replaced data cables, which were prone to damage. These wireless systems significantly enhance operational robustness and ensure consistent weighing accuracy.

Weighing system for the EAF furnace shell

With the rise of GreenSteel applications, the latest generation of Electric Arc Furnaces (EAFs) demand highly reliable and flexible weighing solutions to meet stringent product and process quality requirements. Modern loadcells in combination with digital condition monitoring have made this tough weighing application feasible –allowing in addition an improved energy consumption control.

Speaker Country:

Germany

Speaker Company/University:

Qlar Europe GmbH

Poster session / 11

Design and Implementation of a Fuzzy Controller for Inter-Stand Tension in a Tandem Mill

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This paper presents the design and implementation of a fuzzy logic controller for regulating inter-stand tension in a tandem mill. The developed fuzzy controller utilizes input variables such as tension error, rolling force, exit speed, and speed correction, and applies a rule base derived from operator experience to adjust the gap position and speed references. The controller operates in three distinct modes: normal run, low speed, and sheet mode, employing Mamdani-style inference and the centroid method for defuzzification. Simulation implementation results demonstrate that the fuzzy controller offers greater flexibility and robustness compared to classical PID controllers, effectively handling complex, multi-variable process conditions.

Speaker Country:

Iran

Speaker Company/University:

Atieh Partak Pipe Industries

Recent progress and new developments in CCS/CCU / 12

Third-Generation Structured Amine Sorbent Technology for Direct Air Carbon Capture (DAC): A Case Study, Advantages, and Challenges

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Abstract

In this study, various methods and stages of direct air capture (DAC) of CO_2 are first reviewed. Subsequently, major DAC companies and projects worldwide are examined, with a particular focus on the technologies developed by the Swiss company Climeworks in the field of DAC—especially its latest innovation, the structured amine-based sorbents. The study then compares different DAC adsorption technologies and provides a detailed explanation of third-generation sorbent technology, also known as structured amines. Furthermore, a case study of Climeworks'practical implementation of third-generation structured amine sorbents in the Cypress Project in the United States is presented. Finally, the challenges associated with this technology and potential improvement strategies are discussed. Direct Air Capture (DAC) of CO_2 is one of the most challenging yet vital technologies in combating climate change, since the concentration of CO_2 in ambient air is only about 0.04% (400 ppm), which is much lower than that in industrial flue gases. Among various options, structured amine sorbents are considered highly promising due to their ordered structure, high adsorption capacity, and superior stability. Despite the challenges of low CO_2 concentration, high humidity, and elevated operational costs, these sorbents—through the use of advanced technologies—have achieved significant progress in the field of direct CO_2 capture. The third generation of structured amine sorbents, offering large surface area and optimized chemical stability, has further enhanced the efficiency of this process. In this study, we aim to describe the most recent global project utilizing this type of sorbent and to examine the future potential of structured amine sorbents in CO_2 capture and environmental pollution reduction.

Keywords: Carbon dioxide, DAC, structured amine sorbents, Cypress project, third-generation sorbents

Speaker Country:

Iran

Speaker Company/University:

Arfa iron & steel company

Use of alternative iron sources / 14

Assessment of SiO_2 and Al_2O_3 interchangeability in the DR-EAF Steelmaking Route

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The acid gangue components in agglomerates used in the Direct Reduction–Electric Arc Furnace (DR-EAF) steelmaking route, particularly SiO_2 and Al_2O_3, have a significant impact on EAF performance. These oxides influence slag characteristics such as volume, foaming capacity, and viscosity and affect key operational parameters: metallic yield, electric energy and oxygen consumption, refractory and electrode wear, dephosphorization efficiency and tap-to-tap time.

Considering the growing interest in the DR-EAF route, driven by the steel industry's decarbonization efforts, and the limited availability of high-grade iron ores suitable for this process, it is essential to understand the acceptable limits of SiO_2 and Al_2O_3 in DR-grade agglomerates, assessing how each acid gangue component affects EAF performance. More specifically, it is fundamental to evaluate whether, and to what extent, SiO_2 and Al_2O_3 can be interchanged in the chemical composition of DR-grade agglomerate, considering technical and operational constraints of the EAF process. A clear understanding of the impacts of SiO_2 and Al_2O_3 enables iron ore mining companies to design agglomerates with optimized levels of these oxides, aligned with the operational and economic targets of steel producers.

This study investigates the effects of varying the individual levels of SiO_2 and Al_2O_3 while keeping their combined content (SiO_2 + Al_2O_3) constant, and how these variations influence EAF performance. The analysis was conducted using numerical simulation models for direct reduction and electric arc furnace processes. Isothermal solubility diagrams (ISDs) were used to estimate the MgO saturation levels under specific conditions of FeO content, temperature and ternary basicity in the slag.

The results indicate that varying the individual levels of SiO_2 and Al_2O_3—while maintaining their combined content (SiO_2 + Al_2O_3) constant—has only a marginal impact on slag properties and key operational parameters. Therefore, within defined limits, SiO_2 and Al_2O_3 can be considered interchangeable in the DR-EAF process.

Speaker Country:

Brazil

Speaker Company/University:

Vale S.A.

Safety and Training I / 15

Enhancing EAF safety and efficiency

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The collaboration between Tenova and Polytec at ORI Martin's Electric Arc Furnace (EAF) facility represents a major advancement in the use of robotics and intelligent monitoring in steelmaking. At the core of the project is the PolySAMPLE robotic solution —a 6-axis industrial robot with heavy-duty protection and tool-changing capability —designed to automate critical EAF operations such as temperature measurement and steel sampling. These high-risk tasks, once performed manually, are now executed safely and repeatably under full remote control.
A patented furnace inspection system, co-developed with Tenova, complements the robot by providing a 360° internal view of the EAF shell and refractory lining through high-definition imaging. This enables early detection of wear or damage, improving reliability and minimizing downtime.
Beyond this specific application, similar robotic systems can be employed in other process phases,

including EBT servicing, oxygen lancing, and secondary refining automation, further extending the benefits of safety, precision, and process continuity across the entire steelmaking cycle.

Speaker Country:

Italy

Speaker Company/University:

BM Group

Recycling, circular economy and reduction of environmental impact in steelmaking I / 16

Intelligent Scrap Yard Mapping and Sorting with Vision Systems for Process Optimization

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Efficient management of the scrapyard is essential to improve steelmaking productivity, yet visual mapping and material classification often remain manual and error-prone. This paper presents new solutions developed by Polytec that combine advanced vision systems, AI-driven analytics, and robotic automation to map, classify, and sort scrap materials in real time. The systems integrate high-resolution imaging, spectral analysis, and deep-learning models to identify scrap composition and contamination, enabling automated purification and targeted material handling.
Furthermore, by generating a dynamic digital twin of the scrapyard, the platform ensures accurate material tracking, optimized charge preparation, and improved process traceability from yard to furnace.
Case studies will demonstrate how AI-powered vision and robotics can transform scrapyard operations into a connected, data-driven environment, delivering measurable gains in melt shop performance, quality control, and environmental efficiency.

Speaker Country:

Italy

Speaker Company/University:

BM Group

Poster session / 17

ABS ROADS EVO - Stage II

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This research project aims to develop an innovative and sustainable composite mixture as an alternative to traditional concrete, with the goal of establishing a new long-term standard for permeable civil and road pavements with high technical performance.
The proposed mixture combines geopolymer binders, synthetic aluminosilicate-based materials known for their superior mechanical, chemical, and thermal properties, with significantly lower CO_2 emissions and energy consumption compared to Portland cement. These binders are integrated with a certified product derived from EAF steelmaking slags produced by Acciaierie Bertoli Safau (Danieli Group), offering mechanical characteristics comparable to natural basalt.
The resulting composite is environmentally friendly, avoids the use of virgin raw materials, reduces water and energy consumption, and lowers production costs. It is primarily intended for F900-class permeable pavements, but can also be applied to thin insulation layers and durable industrial surfaces.
The project is structured into three phases:

Laboratory Phase –Mix design development, raw material selection, and granulometric analysis using alkaline reagents.
Validation Phase –Mechanical and geotechnical testing of aggregates and mixtures, assessing strength, permeability, and frost resistance, along with technical and economic evaluations.
Semi-Industrial Phase –Construction of a test pavement at ABS, including installation trials, core sampling, performance verification, and final certification.

The project's originality lies in its integration of innovation, circular economy principles, and sustainability, aligned with the 4Rs: Reduce, Reuse, Recycle, Recover. A key deliverable is the certification by official Technical Bodies, essential for market adoption in public and private infrastructure sectors.

Speaker Country:

Italy

Speaker Company/University:

Acciaierie Bertoli Safau S.p.A.

Use of alternative iron sources / 18

Green DRI-based EAF steelmaking –Feedstock, Design and Operational Results

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To comply with tomorrow's more stringent committed environmental targets for steelmaking, the world witness one of the most fast-paced transitions in the history of steelmaking. DRI-based EAF route will play a crucial role in transforming green steel production thanks to its carbon footprint, which is significantly lower than a blast furnace, while still ensuring the highest product quality. In this presentation, an overview of dynamics of steel scrap market, and the need for ore-based metallics as reliable EAF feedstock is presented. Moreover, a rough guide of the main design criteria for DRI-based EAFs is overviewed. Finally, some actual operational results for cold and hot DRI-based EAFs from Primetals Technologies will be presented.
Keywords:
DIRECT REDUCED IRON –CO2 REDUCTION –ELECTRIC STEEL MAKING –GREEN STEEL

Speaker Country:

Germany

Speaker Company/University:

Primetals Technologies Germany

Innovations in EAF Technology I / 19

Electrifying Steelmaking: Next-Level Performance with EAF Ultimate MOVE, EAF Quantum, and Breakthrough Innovations

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The steel industry is accelerating toward decarbonization, and electric arc furnace (EAF) technology stands at the forefront of this transformation. Primetals Technologies introduces a portfolio of advanced solutions that redefine efficiency, sustainability, and operational flexibility: EAF Ultimate, EAF Quantum, and the innovative Ultimate Move.
EAF Ultimate represents the pinnacle of high-power steelmaking, delivering up to 1,500 kVA/t energy input and ultra-short tap-to-tap times. Its modular design, advanced automation, and integrated Active Power Feeder system ensure dynamic grid control, reduced energy consumption, and minimal flicker. With full raw material flexibility—from 100% scrap to hot metal and DRI—the EAF Ultimate is positioned as a viable replacement for traditional BOF converters, enabling steel producers to meet stringent environmental targets without compromising productivity.
Complementing this, EAF Quantum sets a global benchmark for energy efficiency and throughput. Leveraging patented shaft preheating technology and optimized off-gas utilization, it achieves tap-to-tap times under 30 minutes and energy consumption below 280 kWh/t, reducing conversion costs by up to 20%. Its proven track record of more than a dozen installations underscores its role as the most efficient EAF in operation today.
Building on these foundations, Ultimate Move introduces a revolutionary concept: combining the best features of moveable lower shell, top lance blowing and slag free tapping in a compact footprint. This innovation enables smaller crane capacity & support structures in charging bay, power-on tapping, reducing downtime and accelerating production cycles, while maintaining easier noise isolation and operational safety.
Together, these technologies deliver a quantum leap in performance, sustainability, and cost efficiency—empowering steel producers to achieve green steel goals and maintain competitiveness in an evolving market.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies

Recent progress and new developments in CCS/CCU / 20

Development of Low-Carbon Blast Furnace Operation Technology through Scrap Utilization and EDEM Simulation

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Carbon reduction has recently emerged as a critical global issue, prompting many companies to implement measures to lower their emissions. In Korea, the steel industry accounts for approximately 39% of industrial carbon emissions, with blast furnace operations responsible for about 82% of that share. Consequently, effective carbon mitigation in the steel industry requires the development and application of low-carbon blast furnace technologies. POSCO is pursuing such technologies in parallel with the HyREX process, focusing not only on the use of biomass and hydrogen but also on carbon-reducing raw materials. Among these, scrap offers significant advantages under Scope 3 of the GHG Protocol.

In this study, experiments and EDEM simulations were conducted to enable the effective use of scrap in blast furnaces. Softening Under Load (SUL) tester experiments were performed to simulate the cohesive zone of the blast furnace under varying scrap mixing ratios, from which the optimal usage ratio was determined. EDEM simulations, based on full-scale models of the blast furnace and ore bins, were used to reproduce charging layer formation under different ore–scrap mixing conditions.

The combined results identified the optimal charging layer configuration and operating method for scrap utilization, leading to the establishment of practical blast furnace operation technology. Theoretical analysis indicates that incorporating 5% scrap into the blast furnace can reduce the coal ratio by 22.759 kg/t-p and lower total CO_2 emissions by approximately 4%.

Speaker Country:

Korea South

Speaker Company/University:

POSCO

Automation and Digitalization in Electric Steelmaking III / 21

Mathematical modelling of slag foaming of EAF slags

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Slag foaming is a very important phenomena in the operation of the Electric Arc Furnace due to multiple benefits. It has been extensively investigated from an academic view point, however there are still many unresolved issues dealing with the real conditions that promote these phenomena. I many of the previous investigations the gas is artificially injected, rather than created at the interior of the slag or metal phases. The CO bubbles, which are responsible of the foaming phenomena can be created both in the slag due to FeO being reduced by injected carbon particles or by reactions at the slag/metal interface. This work reports an experimental work focuses on slag foaming due to CO produced at the slag/metal interface, with variations on FeO and basicity.

Speaker Country:

China

Speaker Company/University:

USTB

Future Directions and Emerging Technologies / 22

Journey towards the decarbonization : ESTEP engagement for technical innovation

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The European Steel Technology Platform (ESTEP) continues its mission to drive innovation in sustainable steel production, with ongoing initiatives and collaborations shaping the industry's journey toward climate neutrality. The Clean Steel Partnership (CSP) has further expanded the collaborative research framework established by the Research Fund for Coal and Steel. CSP enables the development and demonstration of transformative technologies at medium to high technology readiness levels. As the private partner in the CSP, established through a Memorandum of Understanding with the European Commission, ESTEP coordinates the industry's research and innovation agenda to achieve the sector's ambitious decarbonization targets: 55% CO_2 reduction by 2030 and 80-95% by 2050 compared to 1990 levels. The specific research and innovation requirements are outlined in detail in the Strategic Research and Innovation Agenda (SRIA) of the CSP, which serves as the comprehensive roadmap for the steel industry's transformation. In this presentation, highlights of CSP-funded projects will be presented that are accelerating the industry's transformation, as well as ESTEP's efforts to shape standardization as a critical enabler for the adoption of breakthrough technologies in European steelmaking. These initiatives span the entire innovation spectrum, from novel hydrogen-based direct reduction technologies to advanced electric arc furnace configurations, demonstrating practical pathways toward green steel production. By demonstrating how coordinated research, targeted funding mechanisms, and cross-sector collaboration are converging to transform the European steel industry, the presentation delivers an integrated perspective on how ambitious climate objectives are being translated into tangible industrial progress. Examples cover CSP projects from carbon direct avoidance and circular economy.

Speaker Country:

Germany

Speaker Company/University:

ESTEP

Poster session / 23

ecoinvent's integrated approach for Life cycle inventory datasets' creation for metal manufacturing processes

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As industries transition towards more sustainable supply chain principles, leveraging reliable LCA databases becomes crucial. Among others, the metals industry also faces increasing demand for transparent environmental data to support sustainability decisions and climate targets. However, the metals industry presents unique challenges to datasets'creation (e.g., diverse extraction methods, complex multi-output processes, reticence to share data, and rapidly evolving recycling technologies requiring comprehensive modelling approaches that capture both primary and secondary production routes).
The ecoinvent association, by managing the ecoinvent LCA database, aims at addressing these challenges through systematic data development in collaboration with industry associations and technical experts. Our approach to improving the coverage of the metals sector involves three key phases: analysing the state of the art through stakeholder engagement and literature reviews, prioritizing data gaps by mapping value chains and identifying critical needs from the industry, and developing datasets following rigorous quality and transparency standards.
This presentation showcases examples of the types of initiatives that lead to data creation for the ecoinvent database, specifically for the metal sector. Recent database releases demonstrate ecoinvent's expanding coverage. For ferrous metals, we provide comprehensive modelling of steel production, including basic oxygen furnace (BOF) and electric arc furnace (EAF) routes, with particular attention to scrap-based production and steel alloy specifications. We have developed alloy-specific datasets through literature-based modelling approaches that reflect real-world material compositions and production requirements. For non-ferrous metals, our collaboration with the International Aluminium Institute (IAI) ensures aluminium supply chain data reflects current industry practices and regional variations, while our partnership with the International Zinc Association (IZA) has enabled the development of Zamak alloy datasets. This coverage spans the full complexity of metals supply chains, from primary extraction and secondary recycling routes to the production of engineered alloys that represent final market products. We explore the different types of data creation processes from both a database management and a user perspective.
As significant data gaps remain, particularly for specialty alloys, emerging recycling technologies, and regional variations in production, ecoinvent actively seeks collaboration with industry associations, research institutions, metal producers, and technology providers to continuously improve data quality and expand coverage. By working together with stakeholders across the metals value chain, we aim to provide the trusted LCI foundation needed for evidence-based environmental decision-making in an evolving sector where primary and secondary production routes increasingly coexist and interconnect.

Speaker Country:

Switzerland

Speaker Company/University:

ecoinvent association

New and emergent ironmaking Technologies I / 24

Mitigation of CO_2 Emissions from Blast Furnaces through Injection of Carbon-Recycled Reducing Agents with High Heat Supply via Partial Combustion

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Mitigation of CO_2 emissions is an urgent challenge for the steel industry, which is one of the most CO_2-intensive sectors. As a promising approach to significantly reduce CO_2 emissions from blast furnace operations, the carbon recycling blast furnace process has been proposed. In this process, carbon recycled reducing agents are synthesized from CO_2 contained in blast furnace gas and injected back into the furnace, thereby reducing the consumption of coal-derived carbon. Since the carbon in these agents originates from internal CO_2, it is not emitted outside the system, contributing to overall CO_2 reduction.

This study investigates the effectiveness of various carbon recycled reducing agents in lowering CO_2 emissions from the carbon recycling blast furnace. First, candidate chemical species that can be synthesized from CO_2 with carbon recycling technology were extracted. Then, the carbon consumption associated with the injection of these agents to the blast furnace was evaluated using a Rist diagram. This theoretical model accounts for heat and mass balance by dividing the blast furnace into upper and lower zones based on the temperature of the thermal reserve zone. Additionally, operational constraints such as the theoretical flame temperature at the tuyere level were considered.

The results indicate that carbon consumption in the carbon recycling blast furnace is primarily influenced by the heat supply from partial combustion of the carbon recycled reducing agents. Carbon consumption decreases as the heat supply from partial combustion increases, due to enhanced thermal input and higher injection rates of the agents. Furthermore, higher blast oxygen concentrations also contribute to reduction of carbon consumption. Based on these findings, it is suggested that carbon consumption and CO_2 emissions can be reduced by up to 40 % compared to conventional blast furnaces by injecting carbon recycled reducing agents with a heat supply from partial combustion exceeding 4000 kJ/kg under high blast oxygen conditions.

Speaker Country:

Japan

Speaker Company/University:

JFE steel Corporation

Poster session / 25

Optimization of Water Heating in Steel Sheet Cleaning through Multi-Stage Heat Exchange and Heat Pump Integration

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A novel water heating system for steel sheet cleaning was developed, which recovers heat from high-temperature wastewater and utilizes a heat pump to heat the supply water. By integrating heat exchangers and heat pump heating, the system significantly reduces energy consumption and CO_2 emissions compared to conventional steam heating. The adoption of indirect heat exchange and multi-pass flow control enhances both operational stability and maintainability. This technology contributes to energy conservation and environmental impact reduction in steel production and can be applied to a wide range of industrial processes.

Speaker Country:

Japan

Speaker Company/University:

JFE Steel Corporation

Slag control and refractories I / 26

Mathematical Modelling of Slag Phase Composition during the EAF Process in Stainless Steelmaking

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Contemporary stainless steelmaking is based predominantly on the duplex route, consisting of an electric arc furnace (EAF) followed by argon–oxygen decarburisation (AOD), or on the triplex route, in which EAF and AOD processing is followed by vacuum–oxygen decarburisation (VOD). Raw materials strongly influence slag chemistry in the EAF, and therefore understanding the properties and evolution of EAF slag during processing is essential both for optimizing slag practice and for enabling downstream utilization of the slag. Recently, an EAF process model developed at the University of Oulu was extended with a metal–slag reaction module that describes mass-transfer-limited metal–slag reactions in stainless steelmaking, i.e., under conditions without foamy slag. The metal–slag kinetics are based on the effective equilibrium constant approach, which extends boundary-layer theory to systems involving several competing oxidation and reduction reactions. However, this approach can predict only the chemical composition of the slag and not the formation of potential solid phases. This paper presents a one-way coupling of the process model with computational thermodynamic software and demonstrates its application for calculating the evolution of slag phase composition throughout the EAF process in stainless steelmaking. The resulting phase-structure predictions provide valuable insights for slag practice in stainless steelmaking.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Automation and Digitalization in Electric Steelmaking I / 27

Optimization of electric arc furnace refining via CFD simulation of steel, slag, and freeboard dynamics

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In recent years, the steel industry has increasingly adopted electric arc furnaces (EAFs). Currently, more than 70% of steel production in the United States is achieved through EAFs. In addition to their energy efficiency and operational flexibility, EAFs can reduce carbon emissions by up to 55% compared with the blast furnace–basic oxygen furnace route, making them a key technology for achieving the steel industry's decarbonization goals. The EAF process consists of melting and refining operations. During melting, electrodes and burners are activated to melt the scrap charge through a combination of arc and chemical heating. In the refining stage, burners switch to lance mode, and oxygen is injected into the molten steel. This oxygen reacts with the steel to reduce carbon content, form oxides, and remove impurities. At this stage, the desired chemical composition and temperature of the steel bath are achieved before tapping. EAF operations involve complex physicochemical phenomena occurring under harsh conditions, making direct data collection extremely challenging. Computational fluid dynamics (CFD) provides a powerful tool to analyze EAF behavior by describing flow dynamics, reaction rates, phase changes, and thermal characteristics throughout the system. However, proper modeling of EAF processes at an industrial scale requires advanced CFD frameworks to capture these strongly coupled phenomena. In this study, a state-of-the-art CFD methodology is developed to simulate the refining stage of industrial EAF operations. The CFD model extends a previous approach that coupled a coherent jet model with a refining model. Namely, the coherent jet model is used to obtain the velocity and mass flow rates of oxygen jets impinging on the molten bath, which are then used to determine the cavities formed by the jets in the liquid steel. The updated CFD methodology, based on the volume-of-fluid approach, incorporates these cavities into the computational domain and includes the molten steel, slag, and gas (freeboard) regions. The updated model accounts for oxide formation in the molten bath during oxygen injection and the migration of oxides into the slag and gas phases. Validation against theoretical data demonstrates accurate prediction of decarburization as well as FeO and MnO generation in both high- and low-carbon regimes. The validated model is then applied to optimize oxygen injection parameters to enhance control over decarburization of the molten steel while preventing excessive FeO generation during refining operations.

Speaker Country:

United States

Speaker Company/University:

Purdue University Northwest

Energy Efficiency and Consumption Reduction / **28**

Successful Full-Scale Implementation of Decarbonization Through Energy Efficiency and Use of Hydrogen

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Over the past years Linde has been supporting decarbonization at its steel industry customers by developing and implementing new technologies focused on energy-efficiency and use of hydrogen. The paper discusses these successful activities, taken place in close and direct cooperation with steelmaking companies, and show examples of the excellent results obtained.
Energy-efficient use of flameless oxyfuel in ladle preheating and reheat furnaces bring about substantial fuel savings from 10% up to 60%: in tundishes even higher. Results from recent such installations are presented here. This is paving the way for effective use of hydrogen as a fuel, which frequently is substantially more expense than an existing fossil fuel.
An important part of the development has been to ensure that the transition to use hydrogen does not lead to any negative consequences, including, e.g., increased NOx emissions and impact on the steel heated and the refractory lining. The key has been to further improve use of flameless oxyfuel combustion, securing no trade-off between reduction of CO2 and NOx emissions, but lowering both, and maintaining steel quality and yield. This technology, the challenges overcome, and the excellent results achieved are discussed along with the development hydrogen-oxygen combustion.

The most prominent example of this work is found at Ovako in Sweden. Following the 2020 successful world's first full-scale test with heating steel before rolling using 100% hydrogen, since early 2024 this has been turned into permanent operation. 48 soaking pit furnaces, heating hundreds of thousands of tonnes of steel annually, are operating with 100% flameless oxyfuel using 100% hydrogen. Compared to previous operation using fossil fuel, no major changes in operation practice have taken place. No negative impact on the steel heated and the refractory lining have been experienced. The hydrogen is supplied by an onsite alkaline electrolyzer powered entirely by fossil-free power. To date more than 500,000 tonnes of alloyed steel have reheated in this operation.
Following this success, Linde together with Ovako and other steelmakers are now implementing same pathway also in continuous reheat furnaces and finding solutions for viable supply of hydrogen; the main obstacle is not the use of hydrogen as a fuel but supply of hydrogen at a low cost and a low carbon footprint.
In addition to use of hydrogen as a fuel steel reheating, successful tests have taken place for use in electric arc furnace burners and injectors, and in ladle and tundish preheating.

Speaker Country:

Germany

Speaker Company/University:

Linde GmbH

New and emergent ironmaking Technologies I / 29

Development of low carbon sinter technology using low melting point additives

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In the ironmaking process, more than 80% of the steel industry's CO2 emissions are produces, and low-carbon blast furnace (BF) operations are needed to achieve carbon neutrality.
Sinter is a major raw material for the BF, and CO2 generation is inevitable because carbon materials (CM), such as coke and anthracite, are used during sintering process. It is necessary to reduce the use of CM to lower CO2 emissions during sintering process. A decrease in CM usage also implies low temperature sintering.
The maximum sintering temperature exceeds 1350℃, and if sintering can be achieved at a lower temperature, CO2 emissions can be reduced by decreasing the amount of CM used. Using an additive with a low-melting point (low-MP) is a key factor for achieving low temperature sintering.
In this study, three types of iron ore and limestone were used to produce low-MP additives. Experiments were conducted by varying the mixing ratio of iron ore and limestone, the sintering temperature, and the sintering time. The conditions for manufacturing additives with a MP of approximately 1213℃ were derived by optimizing the mixing ratio and firing temperature of iron ore and limestone.
In addition, an experiment was conducted using by-products generated in the steel mill. Firstly, recyclable by-products were selected, and the conditions for producing a low-MP additive with a melting point of approximately 1224℃ were derived by optimizing the sintering temperature and the mixing ratio of the by-products.
When a low-MP additive is used, the CM cost can be reduced by more than 5% compared to standard case while maintaining equal or higher sinter quality. Through this improvement, it is possible to realize a low carbon sintering process.

Speaker Country:

Korea South

Speaker Company/University:

POSCO

Ongoing Research in Electric Steelmaking II / 30

Integrated Multi-institutional Approach to EAF bottom blowing technology development: Scaled Physical Model Verification, CFD Simulation, and Industrial Application

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Electric arc furnace (EAF) steelmaking represents a critical pathway toward achieving carbon neutrality in the steel industry by 2050, as it significantly reduces CO_2 emissions compared to blast furnace and basic oxygen furnace processes. However, the localized heating from the electric arc limits the stirring efficiency of molten steel, necessitating enhanced mixing strategies. Bottom blowing technology has emerged as a proven solution to enhance fluid flow, accelerate melting and decarburization rates, and improve molten steel quality. This study presents a comprehensive multi-institutional collaborative framework integrating theoretical modeling, advanced computational analysis, and industrial-scale validation to optimize EAF bottom blowing technology. The research methodology comprises three complementary approaches: (1) University-led scaled physical modeling provides theoretical verification of CFD simulation through the experimental validation using water model and PIV observation, establishing the scientific foundation for the phenomena of fluid dynamics. (2) Specialized simulation company develops high-fidelity CFD models to generate comprehensive simulation datasets characterizing fluid dynamics, gas bubble behavior, and mixing efficiency in bottom blowing systems. (3) Steel industry partner conducts full-scale industrial demonstration to validate laboratory and computational findings, ensuring practical applicability and operational feasibility in conventional EAF furnace. This integrated approach bridges the gap between academic research and industrial implementation, combining the rigor of physical modeling verification with computational precision and real industrial validation. The collaborative methodology establishes a reasonable framework for understanding bottom blowing hydrodynamics and optimizing operational parameters for enhanced energy efficiency and product quality in conventional EAF steelmaking.

Speaker Country:

Korea South

Speaker Company/University:

Chosun University

Recent progress and new developments in CCS/CCU / 31

Comparison of carbon capture technologies for steel and cement off-gases

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The defossilisation of hard-to-abate industries such as steel and cement is a major challenge for achieving climate-neutrality in 2050. In these sectors, some CO2 emissions are unavoidable due to chemical reactions during raw material processing (e.g., limestone calcination) and the use of carbon in steel production. Therefore, efficient and scalable carbon capture technologies are essential to capture and reduce emissions, enable carbon utilisation, and support the transition toward sustainable industrial practices. Within this context, the Austrian flagship project ZEUS –Zero Emissions throUgh Sector Coupling aims to demonstrate integrated, climate-neutral process chains by combining renewable hydrogen production with CO2 capture and utilisation under real industrial conditions. The project addresses the steel and cement industries, which are among the most difficult to bring to climate neutrality, and evaluates practical solutions for cross-sector integration and energy optimisation.
This work presents a comparative assessment of two pilot-scale carbon capture units and technologies treating industrial off-gases with varying CO2 concentrations ranging from 15 to 25 vol.%:
1) an amine scrubber operated with steel mill off-gases, and
2) two membrane separation units, one treating steel mill off-gases and one treating cement plant off-gases.
The amine scrubber demonstrates a CO2 capture rate of approximately 800 kg/day with product purity exceeding 99%, while optimisation efforts focus on minimising energy consumption and maintaining long-term solvent stability under fluctuating flue gas compositions. The membrane units, designed for up to 500 kg/day CO2 separation, employ modular membrane elements to enable flexible operation and high capture efficiency (>90%) at food-grade CO2 quality. Continuous pilot operation under real flue gas conditions provides detailed insights into membrane durability, process dynamics, and energy efficiency.
In parallel, process simulation models of both pilot plants are developed using gPROMS (General PROcess Modeling System). These models are calibrated with experimental data and allow a systematic evaluation of performance metrics, including specific energy demand, separation efficiency, and product quality. Simulation results are further used to explore optimal operating strategies and to assess opportunities for integrating the two technologies into broader industrial process chains.
The combined experimental and modelling results illustrate the strengths and limitations of amine scrubbing and membrane separation for steel and cement applications. By providing quantitative insights into process behaviour, energy requirements, and operational flexibility, this work informs technology selection and contributes to the ZEUS objective of demonstrating integrated CO2 capture and utilisation technologies across industrial sectors.

Speaker Country:

Austria

Speaker Company/University:

K1-MET

Poster session / 32

Development of low carbon raw material substitution technology based on BF process

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The current national project we are working on is being carried out in two main parts until 2030.
The first part involves technology for injecting hydrogen-rich gas into the blast furnace, and the second part focuses on developing technology for charging scrap/HBI into the blast furnace, which will be developed up to the demonstration stage.
The first part will focus on securing the fundamental technology for the demonstration of hydrogen-rich gas injection into the blast furnace by 2027, as well as analyzing and resolving operational issues related to hydrogen-rich gas injection. From 2028 to 2030, the focus will shift to the demonstration and optimization of hydrogen-rich gas injection into the blast furnace.
Detailed tasks include the development of hydrogen-rich gas supply facility technology,tuyere technology for hydrogen-rich gas injection, measurement of hydrogen utilization rate, combustion zone simulation technology for hydrogen-rich gas injection, development of a hot metal [Si] model for hydrogen-rich gas injection, raw material charging and blowing technology, evaluation of iron ore characteristics for hydrogen-rich gas injection, and analysis of CO2 reduction effects from an LCA perspective.
Participating organizations include POSCO, POSTECH, Sungkyunkwan University, Research Institute of Industrial Science & Technology (RIST), Korea University(Prof. Lee, Joon Ho), Seoul Engineering, Pields Engineering, and KOMERA(Korea Metal Material Research Association).
The second part will focus on developing the fundamental technology for the demonstration of alternative iron sources in the blast furnace by 2027, as well as analyzing and resolving phenomena related to charging alternative iron sources into the blast furnace.
From 2028 to 2030, the focus will be on the demonstration and optimization of alternative iron sources in a 2,500m³ medium-sized blast furnace, and on securing application technology for alternative iron sources in a 5,000m³ large blast furnace.
Detailed tasks include analysis of expected effects and operational design for each alternative iron source, development of simulations for scrap/HBI blast furnace reaction behavior, and establishment of processes for scrap selection and shape management for blast furnace.
Participating organizations include POSCO, Hyundai Steel, Samyook SNG, and Seoul National University.

Speaker Country:

Korea South

Speaker Company/University:

POSCO

AI and Machine Learning in Process Optimization I / 35

Multi-Tiered AI Implementation for Slag Property and Alloy Prediction in EAF Operations: Operational Validation Access Three Steel Producers

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EAF operations face critical variability challenges in scrap mix composition and quality that directly impact slag basicity control and alloy chemistry prediction. Traditional multivariate statistical approaches rely on reactive empirical adjustments where conventional analytical tools reach computational limits for real-time process optimization.
This study presents operational validation of a four-tier AI implementation using Fero Labs' Bayesian machine learning software across three EAF producers: a high-end stainless steel sheet mill, a carbon steel sheet producer, and a structural steel facility. The multi-modal approach integrates scrap yard characterization data, real-time melt plan parameters, charge analysis, and tap measurement validation to provide comprehensive process optimization.

Tier 1: Scrap-based prediction activated immediately upon charge schedule determination, enabling proactive slag basicity and alloy content forecasting before bucket loading.
Tier 2: Real-time charge optimization providing operators with optimal chrome additions during melt progression for stainless operations.
Tier 3: Enhanced prediction accuracy using updated scrap characterization and current melt plan data, enabling precise lime addition adjustments and power-on time optimization.
Tier 4: Automated tap data analysis conducting multivariate correlation analysis across 10+ process dimensions with automated investigation report generation.
Stainless Steel Mill: Chrome content coefficient of variance (CV) reduced from 16% to 13% through multi-stage AI optimization, directly addressing the primary cost driver in high-end stainless production.
Carbon Steel Mill: Slag B3 ratio CV improved from 12% to 6%, achieving 50% stability enhancement through predictive slag characterization.
Structural Steel Mill: AI soft sensor implementation increased slag measurement frequency from 33% to 100% of heats, enabling proactive operations management for previously unmeasured heats.
In addition to improving operational stability, early results indicate slag basicity use case achieved 12% reduction in lime dosing, while charge chrome decrease delivered $2-5pertoninhighchromegradesand1$-3 per ton in low chrome grades.
Additionally, adverse event investigation closure time as reported by the engineers was reduced from 1-2 days to under 1 hour through automated multivariate analysis and reports with AI insights. This enabled process engineers to dedicate additional time supporting operations teams with adopting AI workflow, which proved essential for creating a continuous improvement cycle and achieving the process stability improvements demonstrated across all three facilities.
The mills utilize Fero Lab's no-code interface enabling process engineers to independently train and maintain AI models without external support. Browser-based HMI delivers real-time predictions and optimization recommendations directly to operators, facilitating seamless integration with existing EAF control systems.

Speaker Country:

Germany

Speaker Company/University:

Fero Labs

AI and Machine Learning in Process Optimization II / 36

Physics-Informed Reduced-Order Modeling for Temperature Prediction in Industrial Reheating Furnaces

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Industrial steel reheating furnaces operate at temperatures between 800°C and 1300°C and consume a significant fraction of energy for the heating process. These units are significantly energy-intensive, and accurate prediction of furnace gas and slab temperature distributions is essential. This can help to maintain slab quality, support operational decision-making, improve thermal efficiency and enable decarbonization strategies (fuel switching, electrification). However, high-fidelity computational fluid dynamics (CFD) simulations are computationally expensive, which makes systematic design optimization impractical. In contrast, purely data-driven surrogate models can alleviate the computational cost. These methods often extrapolate poorly and can violate physics when applied outside their training envelope.

This study proposes a hybrid Reduced-Order Model with Physics-Informed Neural Network (ROM-PINN) framework for fast and physically consistent prediction of furnace and slab temperature distributions in an industrial reheating furnace. Detailed CFD simulations have been carried out and validated with real observations. These simulations are carried out for multiple syngas–natural gas blends and representative operating conditions for the industrial reheating furnace. The resulting high-dimensional CFD fields are reduced using Proper Orthogonal Decomposition (POD), yielding a compact set of dominant modes. A fully connected feed-forward neural network learns the mapping from operating parameters to the corresponding POD modal coefficients, which are used to reconstruct the full temperature field.
Radiation and conduction equations, as well as physical boundary conditions, are embedded directly into the neural network training through a multi-term loss function. The physics loss penalizes violations of Fourier heat conduction in the steel slab and radiative transfer equation (RTE) for the participating furnace gas, together with the Stefan–Boltzmann law governing the exchanges between the gas and solid surfaces and global energy conservation over the furnace control volume. An adaptive weighting strategy tracks the relative magnitudes of data and physics residuals during training.
The proposed framework can achieve speedups of several orders of magnitude compared with full CFD simulations. In addition, this model can remain robust in extrapolation which means even when applied outside the training envelope, it can avoid non-physical temperature overshooting or violating physical constraints.

Speaker Country:

Belgium

Speaker Company/University:

Universite libre de Bruxelles

New and emergent ironmaking Technologies I / 37

Assessment of Oxide Alloying Elements in the Hydrogen Plasma Smelting Reduction (HPSR) Process

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The steel industry accounts for roughly 7–9% of global CO_2 emissions, largely because traditional production relies on carbon-based reduction methods. Reaching climate neutrality demands alternative process routes that eliminate direct CO_2 emissions. The Hydrogen Plasma Smelting Reduction (HPSR) process is a promising carbon-free approach that uses hydrogen plasma simultaneously as a heat source and a reducing agent, enabling the direct conversion of iron ore to steel in a single step. This work explores the potential of the HPSR process not only for reducing iron oxides, but also for the concurrent reduction of oxidic alloying elements such as NiO, MoO_3, and WO_3. This capability would allow the direct production of alloyed steels from mixed oxide feeds. Experimental campaigns were conducted in a laboratory-scale HPSR reactor at the Chair of Ferrous Metallurgy, Technical University of Leoben, Austria.

The investigations focused on reduction behaviour, temperature evolution, and key process parameters and were supported by gas analysis during operation and detailed characterization of the produced materials using scanning electron microscopy. The results demonstrate the strong reduction capability of hydrogen plasma and confirm that multiple alloying oxides can be efficiently reduced under appropriate operating conditions. Overall, the findings show that the direct production of pre-alloyed steels from mixed oxide charges in a single-step, CO_2-neutral HPSR process is technically

feasible. This approach offers a meaningful pathway toward more sustainable and climate-friendly steelmaking.

Speaker Country:

Austria

Speaker Company/University:

Technical University of Leoben

Poster session / 38

Development of CO2 Emission Reduction Technology in Blast Furnace Process using H2 rich Gas Injection and Alternative Iron Ore Charging

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The environment surrounding the iron and steel industry has greatly changed. The Paris Agreement, a new climate change regime, has been in effect since '21, and the Parties announced the National Determined Contribution (NDC) in accordance with the Paris Agreement. After the establishment of the NDC in 2015, Korea revised its target to "reduce the greenhouse gas emissions by 40% compared to 2018 by 2030,"which has been significantly raised compared to the previous one.
The steelmakers around the world are also declaring carbon neutrality and actively developing the innovative hydrogen reduction steelmaking and CCUS technologies to realize it. The present carbon based BF process with high efficiency and large scale has been occupied approximately 70% of steel production and required the unlimited endeavors for carbon reduction within its technical limits until hydrogen reduction steelmaking conversion as bridge technology.
POSCO has been carried out the national project (COOLSTAR) that is to directly reduce CO2 emission by injecting by-product gas(COG) into tuyeres and charging low reduced iron(LRI) into blast furnace that is partially reduced in fluidized bed reactor using reduction gas converted from by-product gas and improving the qualities of raw materials. This project has been progressed through the pilot-scale of technology development and currently, being developed for application in a commercial blast furnace. In this presentation we would like to introduce some of the results obtained from the pilot scale national project

Speaker Country:

Korea South

Speaker Company/University:

POSCO

Scrap management and quality improvement / 39

Next Generation Raw-Material and Process Optimization in Electric Arc Furnace Steelmaking

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Electric arc furnace (EAF) steel making is increasingly impacted and challenged by volatile scrap markets, scrap quality, energy prices and supply chains. This makes it extremely hard to optimize the operational costs, because of constant daily changes in framework conditions. These dynamics limit the effectiveness of traditional heat-by-heat optimization, particularly when real production orders must be planned across multiple days or weeks. Existing software systems typically optimize either the raw-material selection or alloying strategies for individual heats but lack the capability to perform connected, long-range planning that accounts for stock depletion, future deliveries, hot-heel strategies and intraday energy price variations.

Thus, the demand for sophisticated software solutions that can react to the challenging and fast-changing conditions is extremely high. Recent advances in computational power and artificial intelligence, however, have enabled the development of a more sophisticated solution called "qontrol maps".

This work presents a hybrid metallurgical and machine-learning framework engineered for raw-material characterization, basket charge mixes and heat optimization within a campaign context, where multiple consecutive heats over days or weeks are optimized simultaneously. The model integrates chemical, thermo-kinetic, logistical, economic and environmental constraints across the entire melt-shop route. By coupling real-time inventories, energy and material prices, morphology-based melting kinetics, future deliveries, virtual materials and hot-heel conditions and more, the system identifies optimal material allocations and energy-use strategies that cannot be resolved by traditional optimization approaches.

Real-time scrap, alloying and additive prices, stock levels, future deliveries and scheduled production orders are provided as input. The total number of heats and all operational and logistical constraints (e.g., charging limits, scrap morphology, alloying) are then defined. Based on this information, qontrol maps determines cross-process the cost-optimal practice across the entire campaign. This means that the optimization of raw-materials, charges and heats are linked together and computed simultaneously. Each step in the process: from scrap selection and layering, hot-heel usage, melting behavior, slag formation and casting constraints, contribute to the overall optimization, as decisions in one heat influence the boundary conditions of subsequent heats. Consequently, the entire production route affects the optimal solution, enabling a level of coordinated planning that is not achievable with isolated individual heat optimization.

Industrial applications demonstrate significant reductions in costs, electrical energy demand and CO_2 emissions, together with improved melt-in stability and more efficient use of scrap. The proposed methodology establishes a shift from isolated, single-step optimization toward big-picture predictive campaign optimization for modern EAF operations.

Speaker Country:

Austria

Speaker Company/University:

qoncept technology GmbH

Innovations in EAF Technology II / 40

Application of Modular Multilevel Converters in Electric Arc Furnace Systems

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Electric arc furnaces (EAF) play a pivotal role in the steel industry's transition toward renewable energy and reduced emissions. However, their grid-disturbing behavior makes it increasingly challenging to integrate new systems into weak grids.
To meet these demands, Primetals Technologies has developed the Active Power Feeder (APF) based on Modular Multilevel Converters (MMC) technology. MMCs are widely used in HVDC and other high-performance applications thanks to their modular and scalable design, multilevel voltage output, inherent redundancy, high efficiency, reduced necessity of passive filters, and fault-ride-through capability. For EAF operation, these advantages can be used to full capacity.
First, grid stabilization is essential. The APF enables active power control for EAF operation while compensating other furnaces by injecting reactive power to stabilize grid voltage and frequency.
Second, process optimization ensures the most efficient melting procedure. Acting as an electric actuator, the APF provides precise, high-bandwidth control of arc currents and voltages - superior to slower mechanical actuators. By limiting current spikes, it reduces material wear. Rapid voltage adjustment prevents arc loss and eliminates the need for on-load tap changers at the transformer.

This publication will include information and technical data from the first installed APF-system, used for production at an industrial steel plant (It is intended to provide name and location of the steel plant. However, this needs to be requested according to data protection). Beside the metallurgical and process optimizations, electrical characteristics will also be explained. The new degrees of freedom for control of the EAF like frequency, overcurrent protection, dynamic and unsymmetric operation and several others are part of the investigations done in the oral presentation/paper.
Additionally, a technical view on the used hardware components is planned. This includes power electronic modules, passive components (reactors), cooling strategy and an overall explanation of the circuit.

Speaker Country:

Germany

Speaker Company/University:

Primetals Technologies Germany GmbH

Process Control and Quality Improvement / **41**

Monitoring the Ar-plasma pre-melting of fluxed Cr2O3 and iron oxides in a lab-scale electric arc furnace

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Natural chromite ores can be classified into high-grade, sub-grade and low-grade chromium ore regarding the concentration of Cr2O3. All categories of chromium ores are available for ferroalloy production. Around 80%-90% of ferrochrome (FeCr) which yields from the energy intensive carbothermic smelting of chromium ore is consumed by the production of stainless steel. Stainless steel is widely used in various applications including construction, automotive, aerospace, and kitchenware. A fundamental study on recognizing the impact of common fluxes on the formation of desired and undesired spinels in interaction with Cr2O3 is required. It is due to the modifying the melting behavior of synthetic chromite in the smelting process via electric arc furnace (EAF). CaO and SiO2 are two common fluxes in the chromite smelting process to lower the melting point of Cr2O3 and

increase the efficiency of reduction process.
In this work, the pre-melting of fluxed Cr2O3 and iron oxides are studied by self-developed lab-scale EAF in an argon atmosphere. Besides that, investigating the interaction between slag/oxides and crucible in high temperature, which is made from refractory material MgO, has also been analyzed. The melting process is monitored by optical emission spectroscopy (OES) coupled with camera to record the reactions during the melting. The OES focuses on analyzing plasma composition, presenting how the intensities of different elements evolve as the function of time, and evaluating plasma characteristics. The plasma video will provide a direct look into the reactor, i.e. the dynamic behavior of plasma arc, the status of molten bath and crucible, the filtered pixel intensities from the extracted plasma images. Energy consumption will also be considered for further optimization of energy saving.
With the help of OES in-situ monitoring in EAF, the melting properties of chromite ore can be better understood by initially studying synthetic chromite (Cr2O3-Iron Oxides-CaO-SiO2) system and adjusting to different slag basicities. Optimal mixtures can then be approached and identified in future studies.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Integration of Renewable Energy & Biochar Applications / **42**

Valorization of EAF Slag & Dust for High-Value Applications: Challenges and Technological Solutions

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The steel industry's transition towards lower CO2 emission is accelerating the shift from BF/BOF routes to direct reduction and electric arc furnace (EAF) operations. This green steel transformation will significantly increase EAF-related byproducts such as slags and dusts. Unlike BF slag, widely used as a secondary cementitious material (SCM), EAF slag faces limited utilization due to compositional challenges—particularly high FeO, MgO as well as Cr and V-Oxides—resulting in frequent landfilling or low value applications. EAF dusts, typically rich in Zn, are mainly recycled via the Waelz process to recover crude zinc oxide. While energy-efficient, this process emits high CO_2, produces iron-rich slag requiring disposal, and yields zinc oxide that demands further treatment and remains only partly usable in primary zinc applications—highlighting the need for cleaner, circular technologies.

This paper examines advanced valorization strategies for EAF by products, focusing on thermal reduction processes in electric smelting furnaces which could be a promising solution for both slags and dusts. Smelter-based treatment of EAF slags enables recovery of valuable metals and allows to modify slag mineralogy, making it suitable for usage as SCM or as a decarbonized raw material for cement production depending on the legislative limits. The recovered metal fraction can substitute scrap or be reused as hot metal, supporting circular economy principles by reducing CO_2 emissions and eliminating landfilling. Comparison with other slag treatment solutions like conventional cold processing shows the smelter based thermal reduction is the only option for full metal recovery and highest value output material streams.

For EAF dust, several technologies—including hydrometallurgy and pyrometallurgy—are under development. Primetals Technologies' Zinc Extraction Process (ZEP), combining pre-calcination and thermal reduction, addresses Waelz process drawbacks by fully valorizing iron- and zinc-containing dust with minimal CO_2 emissions. The Smelter step recovers iron and zinc while converting the mineral fraction into a product suitable for construction industry. The pre-calcination step for high-zinc containing EAF dust is designed to remove contamination of halogens and heavy metals enabling higher purity crude zinc quality. Utilizing renewable energy and secondary carbon carriers, ZEP offers a sustainable, circular solution for dust recycling.
Technical, economic, and regulatory challenges for implementing these processes will be discussed, alongside their role in enabling high-value outputs for steel and cement industries, contributing to a low-carbon future.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies

Recycling, circular economy and reduction of environmental impact in steelmaking II / 43

Biochar as a substitute for fossil-based injection coals in EAF operation –definition of criteria for material suitability based on lab tests, particle conversion modelling and industrial injection trials

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In electric arc furnaces typically fossil coal in form of petrol coke or similar is used to create slag foaming in the refining phase. This is responsible for roughly 5-10 % of total CO2-emissions in electric steel production, which means potential savings of 30–60 kg CO2/t steel if carbon neutral sources are applied.
Therefore, a fundamental investigation of the reaction behaviour of different carbon sources in EAFs is studied in this paper. This includes lab tests, various simulations as well as industrial injection trails.
The primary objective is to enable the substitution of fossil-based injection coals with biochar in EAF operation by establishing robust criteria for material suitability, especially concerning the ability of the coal to produce foaming slag. The approach models the thermal and chemical conversion of individual coal particles, employing a layer-based model tailored to EAF conditions. The model parameters are calibrated using experimental data from laboratory-scale decomposition tests of biochar and petrol coke. The model is then applied to calculate the conversion of biochar and petrol coke under EAF conditions (gas atmosphere and temperatures) and assess the performance of biochar regarding slag foaming.
The enhanced layer model, validated by experimental decomposition tests, accurately predicts the conversion behaviour of both biogenic and fossil coals. Key findings include:
• Particle density and diameter are primary influencing factors on conversion time; lower density and smaller diameter accelerate conversion.
• Specific surface area and pore size exhibit compensatory effects; increased surface area can be offset by reduced pore diameter due to diffusion limitations.
• High volatile content in biochar is disadvantageous for EAF use, as volatiles are rapidly released and do not contribute to slag foaming.
• The model supports the definition of optimal particle size and density for each type of biochar, ensuring comparable performance to fossil coal in EAF operation regarding slag foaming.

These findings have also been verified within several injection trials in an electric arc furnace where almost no difference of reaction behaviour was noticeable between petrol coke and biochar. Within these investigations it could be shown that each carbon source needs to be prepared and produced in a different way to get the desired results. Following, it is technically possible to substitute fossil carbon sources as injection material for slag foaming by biochar if the correct type of biochar combined with the appropriate pre-treatment is chosen.

Speaker Country:

Austria

Speaker Company/University:

Stahl- und Walzwerk Marienhütte GmbH / BIOS Bioenergiesysteme GmbH

Safety and Training I / 44

Simulation Based Training for Industrial Operations: Interactive Learning for Complex Tasks

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Training Electric Arc Furnace operators requires time, controlled conditions, and supervised exposure to plant operations. Many critical events cannot or should not be observed during live training because they carry safety risks or depend on rare process conditions. Simulation based training addresses this gap by reproducing the operational environment without exposing personnel or equipment to danger.
The paper presents a simulation-based training environment designed to accelerate the preparation of operators in electric arc furnace plants. The system combines structured learning modules, multimedia training material, and a fully interactive 3D model of the EAF to reproduce the operational sequence from charging to tapping. The platform relies on a backend that records user actions and evaluates progress, but its central function is practical, simulation driven familiarization with real operating conditions.
Training begins with guided content that introduces the fundamental process steps, equipment configuration, and safety constraints of the furnace area. This establishes the technical baseline before the user moves to hands-on simulation.
Indeed, the core component is the embedded 3D interactive model. It provides a direct, operational representation of the furnace and auxiliary systems, allowing the trainee to perform critical tasks such as deslagging, control of foamy slag formation, tapping, tilting etc. Because the environment is simulated, users can also experience the direct consequences of wrong decisions without putting personnel or equipment at risk. This enables learning by doing, including deliberate exposure to rare, hazardous, or cost-sensitive scenarios that cannot be reproduced safely in the production plant. The full furnace phases sequence can be observed, manipulated, and repeated, supporting both procedural understanding and situational awareness.
The system serves steel plants where long-standing operational practice must coexist with modern methods. It reinforces traditional training by offering a realistic, repeatable, and risk-free reproduction of key tasks, while adding the advantages of data collection and performance tracking. The result is a unified tool that standardizes operator onboarding, strengthens safety culture, and improves the transfer of operational know-how across teams.

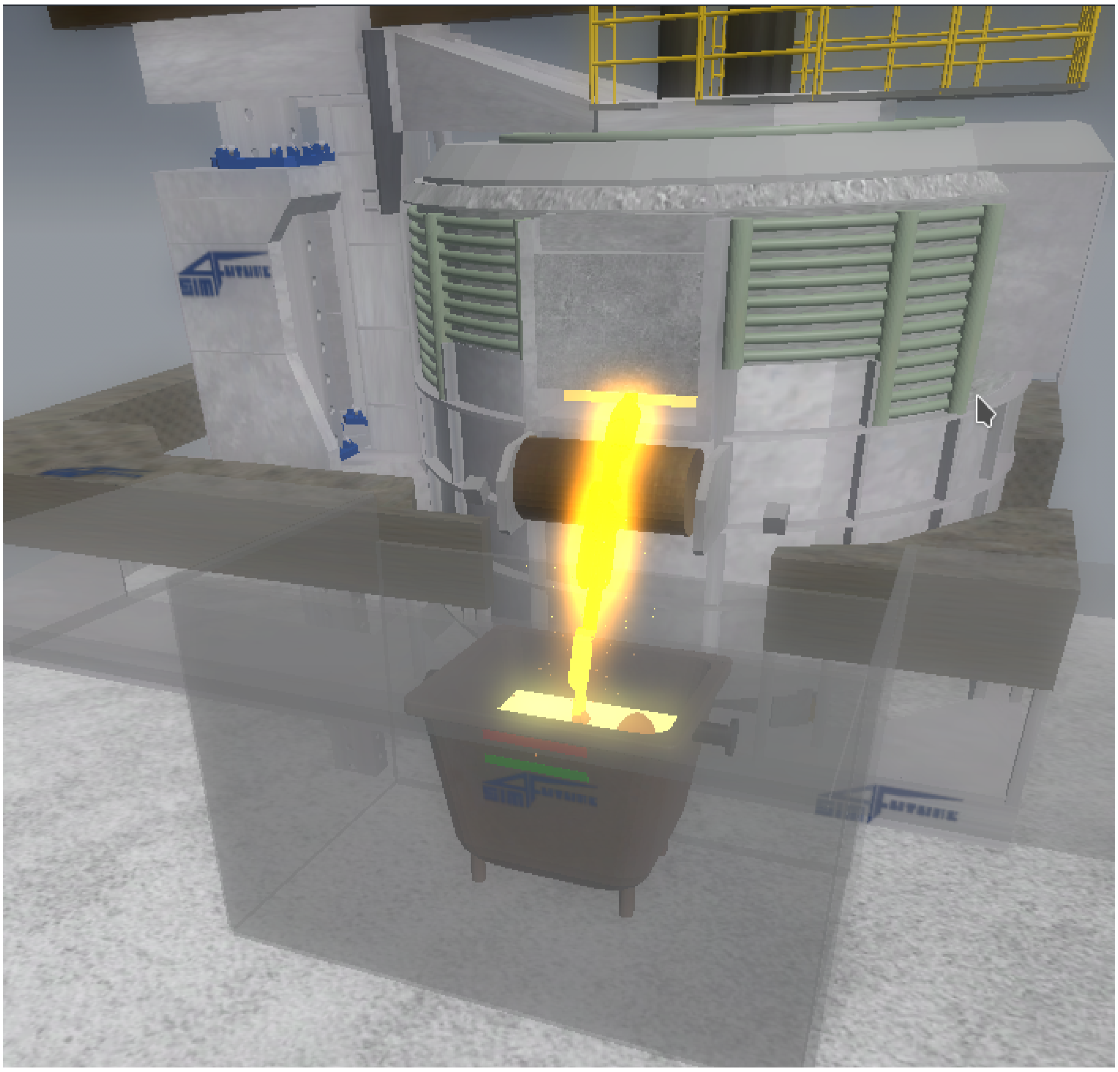

Figure 1: Deslagging phase simulation

Speaker Country:

Italy

Speaker Company/University:

SIM4Future srls

Innovations in EAF Technology I / 45

Evolving AC electric steelmaking –from thyristor based digital power supply solutions to the next generation advanced furnace power control system

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Electric steelmaking is undergoing a significant technological transformation propelled by innovations in power electronics, automation, and digitalization. This paper presents a comprehensive evaluation of two generations of digital power supply technologies for AC electric arc furnaces (EAF), highlighting the successful implementation of advanced control systems that drive productivity, optimize energy consumption, and elevate operational safety.

A decade ago, ABB commissioned a first-generation digital AC EAF utilizing Hatch's SPLC technology. Long-term operational data reveal advantages in several areas including gains in production, reduced electrical and electrode consumption, and enhanced process stability through independent arc voltage and arc current control. These improvements have contributed to more sustainable steelmaking practices and lower operational costs.

Recognizing the need for superior power quality, the next generation of digital power supply system was developed. This innovative solution combines precise furnace power management with advanced power quality enhancement, including active power control, reactive power compensation, flicker reduction, and harmonic mitigation for furnaces connected to medium and high voltage grids. The unified series and shunt control architecture delivers robust arc stability, increased productivity and grid-friendly performance, supporting seamless integration with renewable energy sources and facilitating decarbonization efforts within the steel industry.

Comparative analysis of field data demonstrates the effectiveness of these power electronic solutions in achieving reliable, efficient, and environmentally responsible steel production. Enhanced automation and digitalization enable precise melting process control, further reducing energy usage and maintenance requirements, while improving safety by minimizing personnel exposure to hazardous conditions and supporting proactive risk management.

This work underscores the role of cutting-edge digital power supply systems in advancing electric steelmaking, aligning with industry priorities of energy efficiency, grid integration, sustainability, and workplace safety.

Speaker Country:

Switzerland

Speaker Company/University:

ABB Switzerland Ltd.

AI and Machine Learning in Process Optimization I / 46

Closed-Loop Optimization for Energy Efficiency and Scrap Utilization in Steelmaking at Marcegaglia Sheffield

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This paper presents the deployment and benefits of a comprehensive closed-loop process optimization system at Marcegaglia Sheffield, UK, covering Scrap Yard, Electric Arc Furnace (EAF), Argon Oxygen Decarburization (AOD), and Ladle Furnace (LF) operations.
The paper focusses on Scrap Yard and EAF as key stages, and discusses how advanced sensor systems in combination with closed loop control enable significant improvements in energy efficiency and raw material utilization. By leveraging model based algorithms and dynamic process adjustments, the system optimizes scrap mix composition and minimizes energy consumption during melting. This paper highlights the potential of digitalization and intelligent control strategies to transform traditional steelmaking into a more sustainable and resource-efficient process.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies

Ladle metallurgy and slag control / 47

EAF versus Smelter + BOF –A Comparative Assessment for Low-Carbon Steelmaking

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Transitioning from traditional integrated steelmaking using blast furnaces to direct reduction combined with electric arc furnaces is among the most promising strategies to reduce CO_2 emissions in iron and steel production. However, the availability of raw materials required for this route, such as high-grade iron ores, is limited. To overcome this constraint, alternative green production routes employing a two-step process with a Smelter followed by a BOF are gaining attention. The Smelter enables efficient melting and final reduction of low-grade DRI and allows recycling of iron oxide-rich by-products such as dusts, slags, and mill scale. Additionally, this two-step process offers several options to decouple ironmaking from steelmaking, enabling the energy-intensive ironmaking step to be located in regions with competitive access to green energy.

This paper presents a detailed comparison between the one-step EAF route and the two-step Smelter–BOF route. The analysis begins with input material flexibility: EAF offers high adaptability in charge mixes, while the Smelter provides superior tolerance for varying ore grades and by-product recycling. Metallurgical aspects and steel quality considerations are examined, including differences in refining practices in EAF versus BOF and their implications for secondary metallurgy. By-product management is another key differentiator: Smelter slag can be granulated for high value use in cement production, whereas EAF and BOF slags typically require separate treatment to avoid landfilling.

Finally, the paper compares operational expenditures, including CO_2-related costs, and capital expenditures for both brownfield and greenfield installations. The findings highlight trade-offs between raw material flexibility, process efficiency, and cost structure, providing insights into how these routes can complement each other in achieving large-scale decarbonization of iron and steelmaking.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies

Slag control and refractories I / 48

Towards Better Furnace Design: Minimizing Energy Consumption Through Controlled Freeze Lining Formation

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The formation of freeze lining (FL) –a solidified slag layer that protects the furnace inner walls and refractory linings from chemical corrosion and physical degradation –is essential for the safe, energy-efficient, and long-term operation of high-temperature metallurgical reactors. Building upon a successful prior research program, a new consortium has been established, bringing together Montanuniversität Leoben (MUL) and KU Leuven (KUL) with the industrial partners RHI-Magnesita, Aurubis, and Primetals Technologies. This new partnership addresses fundamental and industrial challenges associated with FL formation to accelerate the transition toward the next generation of sustainable pyrometallurgical processes.
The previous work successfully established a physics-based Computational Fluid Dynamics (CFD) model framework and validated it against laboratory measurements and industrial data from an electric smelting furnace and a slag fuming reactor. The simulation results demonstrated good agreement with experimental data for FL thickness, heat fluxes, and global energy balance, thus providing a solid foundation for further refinement.
The newly-established research project introduces significant new experimental capabilities at both scales. Laboratory experiments use transparent analog systems and custom crucibles with direct visual access for in-situ observation of FL evolution, complemented by industrial-relevant cooling probes and high-resolution diagnostics for accurate measurements. These methods provide unprecedented insights into solidification kinetics, microstructure development, mobile-crystal transport, and the coupling between flow and phase change. These are phenomena critical to FL formation but remain insufficiently understood. At the industrial scale, new industrial-scale test campaigns in the slag fuming furnace (process used to recover valuable metals from slags) and in the emerging hydrogen-based electric smelting furnace (a key technology for the new carbon-neutral steel production) will supply critical real-word data for comprehensive model validation.
The integration of advanced laboratory measurements and multi-process industrial-scale validation will deepen the understanding of the physics governing FL formation and enable a substantial refinement of the CFD model framework. This collaborative effort between academia and industry directly addresses the existing knowledge gaps in slag solidification and FL dynamics. The resulting refined model will be a powerful tool to optimize furnace design, minimize energy consumption through controlled FL formation, and ultimately lead to tangible benefits in the respective industrial process and accelerate the transition toward low-carbon and circular metallurgical processes.

Speaker Country:

Austria

Speaker Company/University:

Montanuniversity of Leoben

Ongoing Research in Electric Steelmaking II / 49

A Time-based Pellet Melting Approach to Model Feed Pile Formation in Electric Smelting Furnace

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Tata Steel Netherlands (TSN) produces approximately 7 million tonnes of steel annually, which is equivalent to the national consumption, resulting in about 12 million tonnes of CO_2 emissions per year, which accounts for around 7% of the Dutch total. Nearly 90% of these emissions originate from producing hot metal in blast furnaces.

To reduce emissions by 70% by 2035, TSN, under the Groeien met Groen Staal (GGS) program funded by the Dutch government through the National Growth Fund, plans to replace its two blast furnaces with more sustainable production routes. One potential route involves reducing iron ore pellets in a Direct Reduction Plant (DRP) to produce Direct Reduced Iron (DRI) pellets, which is then melted in an Electric Smelting Furnace (ESF). In the ESF, DRI pellets and additives are charged from the top, forming a solid feed pile that penetrates the slag and hot metal layers, where heat is transferred from electrodes to the pellets via the slag and hot metal layers, causing them to melt.

One key uncertainty in this process is the formation and behaviour of the feed pile under varying operational conditions, which involves a balance between feeding, pellet melting, and interactions of pellets with the slag and hot metal layers. This study investigates feed pile formation using a coupled Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) method with a time-based melting approach.

Two scenarios are modeled: one allowing slag penetration into the feed pile, and another excluding it, resulting in a dry pile consisting only of pellets and gas in the pore space, with a transition zone of a few pellet diameters to the slag and hot metal layers (Figure 1).

https://imgur.com/a/JjUkJG4
Figure 1 –Illustration of feed pile interaction with the slag layer under two conditions: (a) slag penetration into the pile, where buoyancy forces (Fb,a) act upward within the pile; (b) dry pile condition, buoyancy forces (Fh,a) act primarily at the pellet-pile interface.

A time-based melting model describes the DRI melting process in three stages: (1) shell formation, (2) shell remelting, and (3) pellet core melting. To extend the model and incorporate more physics, a cohesion model based on the Johnson-Kendall-Robertson (JKR) theory is implemented to account for inter-pellet cohesive forces during melting. A preliminary parameter study is also conducted to evaluate the influence of key variables on feed pile shape.

Speaker Country:

Netherlands

Speaker Company/University:

Delft University of Technology (TU Delft)

Ongoing Research in Electric Steelmaking I / 50

A Global Multiphysics Model of Flow Mechanisms in Industrial Scale DC Electric Arc Furnaces

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Electric arc furnaces (EAFs) play a very important role in modern steel making by offering both an environmental and operational advantages over blast furnaces. An important gain by EAF utilization relies in lower carbon emission, potentially a zero-carbon footprint when relying on renewable energy sources. Moreover, EAF offers greater operational flexibility and higher energy efficiency through precise electric heating and production of high-quality steel with minimal impurities making it essential for sustainable and green steel production.
This study presents a comprehensive 2D axisymmetric model of an industrial-scale direct-current electric arc furnace (DC-EAF), fully integrating the electric arc, slag layer, molten metal bath, and refractory walls. The model simultaneously solves coupled electromagnetic, thermal, and hydrodynamic fields across the entire furnace domain, building upon prior validated sub-models for the arc and liquid metal regions. Simulations were conducted for DC arcs operating at 30 kA and 60 kA. Key findings highlight the furnace's flow dynamics, including arc characteristics, impingement effects, magnetohydrodynamic interactions, and buoyancy-driven convection. Three primary flow mechanisms are identified: (1) arc-induced shear stress driving slag radially outward at the surface; (2) electro-vortex effects generating inward convergence beneath the arc in both slag and metal phases; and (3) pronounced thermal buoyancy near the arc and walls, arising from steep temperature gradients. Additionally, arc impingement depth into the bath exhibits strong dependence on current intensity. The model yields valuable insights into internal EAF conditions that are experimentally challenging to probe under extreme operational environments.

Speaker Country:

Austria

Speaker Company/University:

Technical University of Leoben

Innovations in EAF Technology II / 51

Moving to next EAF digital furnace: first heat at Hybar with SMS's group X-Pact AURA

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The paper presents the new EAF digital furnace implemented at Hybar's new 630,000 tpy rebar micromill in Osceola, Arkansas. The X-Pact® AURA was pre tuned before delivery using advanced development and testing methods with RTDS simulations (Real Time Digital Simulator), which allowed it to be commissioned in two days only and the EAF to be rumped up in only four heats. The X-Pact AURA family of IGBT based power modules is capable of feeding EAFs from 5 MVA up to 350 MVA. This fully modular technology provides the required efficiency, dynamic control, and flexible power to meet the needs of the green steel transformation and grid code requirements. Using this innovative technology and proprietary control algorithms, which take full advantage of power electronic capabilities, ensures the highest power transfer and the lowest impact on grid, especially regarding flicker limits. Hybar's steelmaking facility operates entirely on renewable energy, made possible by the seamless integration of a solar farm with X Pact AURA's clean and flexible EAF power supply. Moreover, EAF performance has been improved by the addition of fault ride through capability, which demonstrated power supply resilience and enhanced plant availability by avoiding EAF stoppages.

Speaker Country:

Italy

Speaker Company/University:

SMS group S.p.A.

Ongoing Research in Electric Steelmaking I / 52

Effect of bottom-blowing pattern on the motion behavior of HBI at the bath surface in an EAF-typed water model

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Technological advances in steel production have greatly contributed to industrial growth, yet the steelmaking process still faces a critical challenge: the emission of large amounts of CO_2. Achieving carbon neutrality and transitioning toward a sustainable steel industry require a fundamental shift in production methods that can sustainably reduce CO_2 emissions. In this context, hydrogen-based direct reduction, which utilizes hydrogen as a reductant to produce DRI/HBI that is subsequently melted in an electric arc furnace (EAF), is regarded as a next-generation technology with strong potential to drastically lower CO_2 emissions in steelmaking systems. However, the implementation of this technology requires shifting from the conventional BF-BOF route to an EAF-based process, accompanied by enhancements in the stirring capability of the EAF. Due to the relatively low physical stirring force of EAF, non-uniform energy transfer in the process of melting and separating gangue within the DRI can lead to repeated local melting and solidification. As a result, the iceberg phenomenon occurs, leaving portions of the direct reduced iron unmelted. This condition decreases operational productivity and increases the required melting energy, thereby compromising the operational stability of the EAF. Therefore, enhancing the stirring force within the EAF is essential for stable DRI/HBI melting, and bottom blowing technology has been recognized as a representative solution. In this study, an EAF-typed water model was used to investigate the motion behavior of density-matched surrogate DRI/HBI samples under bottom-blowing conditions. The effects of symmetric and asymmetric pattern of gas flow rate on the motion behavior of those samples were identified. Furthermore, the perfect mixing time was measured under various gas flow rate conditions to determine the optimal operating conditions. These results suggest that controlling the gas flow rate can improve melting efficiency by influencing the motion behavior of DRI/HBI.

Speaker Country:

Korea South

Speaker Company/University:

Chosun University

Innovations in EAF Technology I / 53

Next Generation Direct Feed MV Power Supply for Large Steelmaking EAFs

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The expansion of EAF production, alongside with the large-scale deployment of renewable energy sources, has significant impact on network stability and local capacity. Steel producers will face growing pressure to minimize disruptions to the electrical grid and meet ever increasing utility requirements. To tackle these challenges a novel multilevel converter for the decoupling of EAF operation from the medium voltage grid supply was developed, installed and commissioned in a German steelmaking plant in Dec. 2024. This Direct Feed (DF) Power Supply enables steelmakers to increase both, power quality and EAF performances. Key benefits demonstrated during full heat cycle operation in the nominal power range (up to 130 MW) include flicker reduction up to the factor of ten for 10 min. values resp. eleven for 1 min. values, EAF operation with individually controlled electrode currents, and related EAF performance benefits that will be highlighted in the EEC 2026 conference paper with the title "Direct Feed to Enhance Power Quality and EAF Performances".
The DF modular multilevel converter (MMC) design is based on robust press-pack IGBT technology that has been adapted to meet the special needs of electric arc furnace power supplies and can be scaled up to a power level of 260 MW, without generating reactive power in the medium voltage grid (power factor above 0.99 at the HV busbars without additional power compensation systems). The latest DF converter design has a redundant control architecture and can be operated at nominal power with n-1 submodules in each converter arm. This enables to restart the converter after a component failure in any of the 12 converter arms and continue EAF operation without a loss in performance, enabling to fulfill highest availability requirements for the power supply. Thanks to the variable output voltage and frequency of the DF power supply, the control tasks for the existing EAF transformer tap changer is significantly reduced. The DF converter control system has demonstrated that it can reliably control and limit the electrode currents to predefined values, which significantly reduces the stress on the entire power supply network. Thanks to these gains in controllability, power quality and EAF performance, five large steelmaking plants have decided to build on this new type of MV MMC DF power supply, the largest one is an EAF with a peak nom. power of 260 MW.

Speaker Country:

France

Speaker Company/University:

GE Vernova

Automation and Digitalization in Electric Steelmaking II / 54

Refractory lining monitoring on different metallurgical vessels (EAF, LF, RH Degasser, Induction furnaces, plugs) with Saveway

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It's not a question anymore, it's already a fact that the transition towards CO2 reduced steelmaking will come along with a great number of changes in numerous areas of the production chain. Focusing on the melt section, one of the biggest challenges is the entry of new/different equipment to process from scrap to casting. To cope with these, it is mandatory to use state-of-the-art technology for controlling the process parameters alongside. One of these available technologies is focusing on the status of the refractory lining to determine how it can withstand the new process conditions. The monitoring can be performed in different metallurgical vessels, such as Electric Arc Furnaces, Ladle

Furnaces, RH-Degassers, Coreless Induction Furnaces or considerably simple units like porous plugs. In certain applications it might be required to monitor some small weak spots only, provided You can tell where these are! Other applications obviously require a more comprehensive monitoring. Several areas of the refractory linings will be facing an aggressive impact of the process and thus are prone to experience a significantly quicker refractory deterioration than others do. For conducting an efficient and reliable production it is key to determine these areas quickly and take measures and action to eliminate these weak spots as they have a high potential to cause unexpected shutdowns of the equipment. Furthermore, there is a potential thread to the integrity of refractory linings which is more often neglected. This is the simple affect of moisture or water to their condition. Cooling water leaking into the refractory lining not only causes visible damages (e.g. Explosions). The invisible damage by compromising the mechanical and thermal properties of linings, means turning bricks into non- refractory powder, might even be the more sinister scenario.
This paper will provide insight in Saveway's solutions to address the problems mentioned above by using state-of-the-art but well-established technologies to monitor melting equipment for refractory hot spots, penetration and influences caused by dangerous cooling water leakages.

Speaker Country:

Germany

Speaker Company/University:

Saveway GmbH & Co. KG

Circularity and by-product management in the steel industry / 55

A comparison of simulated and analysed phase compositions of solidified EAF slags

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Transition towards fossil-free iron and steel production increases the role of electric arc furnaces (EAF), whereas the role of blast furnaces (BF) decreases. This has drawn an increasing attention towards the valorisation of EAF slags with the target in the high value applications such as supplementary cementitious materials (SCM). This is supported not only by the declining production of the granulated blast furnace slag (GBFS) currently widely used as a SCM, but also common targets for both cement and steel industry to reduce carbon dioxide emissions.

Due to their different chemical and mineralogical composition, structure and properties in comparison to GBFS, the EAF slags cannot be used as SCMs as such (Kallio et al. 2025). It is widely considered that usage as SCM requires treatments such as modification of the composition towards lower basicity, removal of certain components (e.g. via reduction), controlled and sufficiently fast cooling as well as a feasible way to even out the potential differences due to use of different kind of raw materials in the EAF (steel scrap, DRI reduced with either hydrogen or other reductants, Fe-containing secondary materials such as briquetted dusts, etc.).

The properties and potential applicability of EAF slags are affected by several variables:

- Used raw materials (steel scrap, DRI) and their composition.
- Aimed basicity of modified slags.
- Amount and nature of materials used to modify the basicity (e.g. quartz, silica-containing tailings).

- Aimed reduction degree of reduced metals (e.g. iron), when recovering metals by reduction.
- Amount and nature of materials used as reductants (e.g. coal, biochar, aluminium, ferrosilicon).

The purpose of this study has been to supplement the experimental studies (Merenluoto 2024; Merenluoto et al. 2026) with thermodynamic simulations in which both equilibrium and Scheil-Gulliver calculations were made for different slag systems with varying compositions. Although not being able to simulate the formation of amorphous glass phase obtained with fast cooling of low basicity slags, computational thermodynamics nevertheless offer a tool to quickly estimate the effect of different slag treatments on the stabilities, amounts, compositions and solidification orders of solid crystalline phases as well as solidus and liquidus temperatures.

Kallio, R., Cantaluppi, M., Louhisalmi, J., & Visuri, V. V. (2025). Mineralogical characteristics of fossil-free steel slags. Minerals Engineering, 230(April), 109396. https://doi.org/10.1016/j.mineng.2025.109396

Merenluoto, A. (2024). Effects of Modification and Granulation on Properties of Dri-Based Eaf Slag (Issue July). University of Oulu.

Merenluoto, A. et al., to be submitted 2026.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Waste Management & Environmental Compliance / 56

Control of Free-CaO in Steel slag via heat treatment

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In Korea, approximately 20 million tons of slag are generated annually from ironmaking and steelmaking processes, underscoring the need for effective recycling strategies. Since CaO, a major component of slag, reacts with CO2 to form CaCO3, the utilization of slag as a CO2 sorbent has paid great attention.
Specifically, free-CaO (f-CaO) within the slag also participates in carbonation reactions, contributing to CO2 capture capacity. However, research on the direct application of iron and steel slags for CO2 capture and utilization remains limited. Furthermore, the presence of f-CaO poses significant issues, such as strength degradation due to volume expansion, when slag is utilized as a construction material. Therefore, the removal of f-CaO is crucial not only from a CO2 capture perspective but also for enhancing the applicability of slag in the construction industry.
In this study, a leaching–precipitation process was employed to steel slag to evaluate and optimize its CO2 capture performance. The effects of leaching temperature, particle size, and agitation method on the amount of captured CO2 were systematically investigated. In addition, heat treatment was employed to induce phase transformations in the slag by varying the temperature and duration, and the resulting changes in f-CaO content and crystalline phases were subsequently analyzed. Furthermore, to investigate the correlation between the structural changes in the molten slag and the quantitative analysis results of f-CaO, molecular dynamics (MD) simulations were employed to examine the relationship between Ca-O and other metal ions at various heat treatment temperatures.
Based on the quantified CO2 capture efficiency under various operating and thermal conditions, this

study assesses the potential of steel slag as a high value-added resource for CO2 sequestration and utilization.

Keywords: Free CaO, CO2, CCUS, Steel slag

Speaker Country:

Korea South

Speaker Company/University:

Inha university

Use of alternative iron sources / 57

Impact of New Iron Sources on Basic Oxygen Furnace Operations

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The global shift toward decarbonised steel production with the increasing use of low-grade iron sources has driven interest in introducing electric smelting furnace (ESF) to process low-grade direct reduced iron (DRI) and generate ESF hot metal as a replacement of the blast furnace (BF). At the same time, the gradual scarcity of high-quality scrap has increased interest in using hydrogen based DRI as a coolant in the BOF. While attractive from both sustainability and resource-flexibility perspectives, the thermochemical implications of incorporating ESF hot metal and hydrogen based DRI as alternate feeds with variation in composition, temperature, and gangue content into the BOF are still not well quantified. A better understanding of these effects is critical for ensuring stable operation and preserving steel quality while executing decarbonisation strategies.

Building upon previous research at Swinburne, this study evaluates how alternate feed characteristics influence BOF performance through mass and energy balance (MEB) analysis and kinetic modelling with focus on droplet bloating and decarburisation. A detailed MEB model of the overall process was developed and validated against industrial data. Parametric simulations were performed across representative ranges of carbon and silicon levels in ESF hot metal and across different types of DRI, such as natural gas DRI and hydrogen DRI, allowing assessment of BOF process sensitivity to alternate feed chemistry.

The results demonstrate that reduced carbon and silicon contents significantly lower the thermal reserve of the BOF, decreasing the available chemical heat. Consequently, scenarios with low C and Si exhibit reduced scrap melting capacity and steel yield. Increasing the temperature of ESF hot metal can partially compensate for the loss of thermal input. Slag generation shows a stronger dependence on silicon, since a higher Si level produces more SiO2 in the slag and increases flux demand to maintain the basicity. Preliminary results show that DRI can be used as an effective cooling agent to reduce the bath temperature mainly due to higher gangue levels or lower metalisation rate. Overall, these trends highlight the importance of selecting appropriate amount and temperature when operating with alternate iron sources in order to maintain a stable heat balance and achieve the required process performance.

Future work will extend the current model through dynamic modelling that includes time dependent droplet behaviour and decarburisation kinetics. These developments aim to support optimisation of

BOF operations when using alternate iron feeds and contribute to the broader goal of achieving green steel production.

Speaker Country:

Australia

Speaker Company/University:

Swinburne University of Technology

New and emergent ironmaking Technologies II / 58

Heat Transfer Mechanisms in Electric Smelter Furnaces for Ironmaking

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ABSTRACT

Key words: Electric Smelter Furnace (ESF), Joule Heating, CFD, Radiation, Convection

Steel production involves the reduction, melting, and refining of iron ore. In this processing route, the Electric Smelter Furnace (ESF) is employed to melt the ore and produce molten iron for subsequent refining. Unlike traditional blast furnaces, which rely heavily on carbon-intensive coke, electric smelters utilize electrical energy to drive the smelting process, offering a substantial reduction in carbon emissions. Furthermore, they possess the capability to process low-grade iron ores, a feature that is becoming increasingly vital as high-grade mineral reserves deplete globally. As a subset of the ESF, the Open Slag Bath Furnace (OSBF) functionally represents a hybrid technology. It combines the operational principles of the Submerged Arc Furnace (SAF), typically used for ferroalloys, and the high-energy capabilities of the Electric Arc Furnace (EAF) used in steelmaking. A distinguishing feature of the OSBF is its utilization of the 'brush arc' mode. In this configuration, the electric arc is partially submerged in the slag. This allows for the effective dispersion of thermal energy directly into the molten slag bath while simultaneously minimizing radiative heat losses to the furnace walls and roof. This study focuses specifically on the brush arc within the OSBF to characterize the primary heat generation and transfer mechanisms. To investigate these phenomena, a single-electrode Computational Fluid Dynamics (CFD) model was developed, incorporating Magnetohydrodynamic (MHD) principles to simulate the interaction between the electric arc and the fluid domain. This study provides a pathway to understand heat transfer mechanisms in the smelter, enabling the minimization of energy losses and the mitigation of thermal damage to the furnace roof and refractory sidewalls, ultimately ensuring a more efficient smelting operation.

Speaker Country:

India

Speaker Company/University:

Swinburne University of Technology

Ongoing Research in Electric Steelmaking II / 59

Evaluation of Ammonia-Based Direct Reduced Iron (NH3-DRI) and Its Implications for Subsequent Steel Making Process

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Ammonia (NH3) has emerged as a promising low-CO2 reductant for ironmaking, attracting growing interest in recent years. Unlike hydrogen, ammonia provides practical benefits for long-distance transport and storage, including a much lower liquefaction temperature and a higher volumetric hydrogen density that minimises losses during handling. Our previous thermodynamic evaluation demonstrated that low-temperature NH3 reduction of iron oxides (T < 850 oC) represents a highly promising pathway for decarbonising the ironmaking. A kinetics study at Swinburne further showed that using 100% NH3 leads to a faster reduction rate than the 40% NH3 –Ar gas mixture, with the strongest effect observed between 650 and 850 oC. The study showed a strong temperature dependence on the kinetics, where complete reduction can be achieved in 45 minutes at 850 oC, while reactions at 650 oC progressed more slowly. Iron and iron nitride phases were clearly present in DRIs reduced at 750 ℃ and below, with a thicker nitride layer forming in samples reduced at 650 ℃, whereas pellets reduced at 850 oC consisted only of metallic iron as the final product phase. A previous study reported that the presence of an iron nitride layer enhanced the reoxidation resistance of the pellets, offering potential benefits for passive storage, transport, and handling of DRI. However, it is well known that nitrogen can negatively influence the steel quality, therefore control of nitrogen inputs into the EAF is a critical consideration. Preliminary preheating experiments at 900 oC under an argon atmosphere confirmed that the iron nitride phase can be eliminated within 15 minutes. However, further investigation was conducted in this study to assess the NH3 preheating concept in more detail, particularly because current industrial preheating systems operate at relatively low temperatures (300 to 700 oC), where iron nitrides are likely to remain stable. This study also examined the stability of NH3-DRI under prolonged exposure to ambient conditions (25 oC of temperature and 50% of humidity) to determine its reoxidation behaviour. In addition, the mechanical strength was also determined using the laboratory scale tumble tests to evaluate its ability to withstand handling and transport. These findings will be discussed along with the implications for subsequent transport/handling of DRI and the steel-making process.

Key words: ammonia direct reduction, ammonia ironmaking, NH3-DRI, decarbonization, ironmaking

Speaker Country:

Australia

Speaker Company/University:

Swinburne University of Technology

Recycling, circular economy and reduction of environmental impact in steelmaking I / 60

Potential use of Bio-Coke in Electric Arc Furnace for Steel Production

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The global steel industry is under pressure to reduce carbon emissions. Electric Arc Furnaces (EAF) plays a major role in current steel production with low carbon footprints. Currently, around 30% of global steel production is carried out using EAF. With the growing demand of lower carbon footprint Direct Reduced Iron (DRI) process and increased amount of scrap, demand for EAF steel making is expected to rise. Despite progress toward green steel technologies, carbon remains essential in EAF operations for providing chemical energy, carburization of Steel, slag foaming, and oxygen control. Conventional carbon sources such as metallurgical coke, anthracite, and pulverized coal are fossil-derived and contribute substantially to direct CO_2 emissions. As a result, renewable carbon materials such as biocoke, produced from thermo-chemically treated biomass, are gaining increasing attention as potential substitutes. This paper evaluates the technical feasibility and process implications of using biocoke in the EAF process. The role of conventional carbon sources in EAF steelmaking is first reviewed, that includes (a) charged carbon added with scrap or DRI for providing chemical energy and carburization, (b) injected carbon for slag foaming and FeO reduction, and (c) carbon used as electrodes. Typically, chemical energy supplied through carbon oxidation contributes 15 to 25% of total EAF energy input, while effective slag foaming reduces heat loss and promotes stable arc conditions. The paper also evaluates the performance of biocoke relative to conventional coke based on its carbon content, calorific value, reactivity, ash composition, and mechanical properties. In addition, thermodynamic modelling was conducted using FactSage software to evaluate the interactions of biocoke with molten steel and slag under representative EAF operating conditions. Finally, the study explores the potential of biocoke for slag cleaning applications, focusing on iron recovery from high-FeO containing slags. Together, these insights provide a scientific foundation to support the adoption of biocoke in EAF steelmaking.

Speaker Country:

Australia

Speaker Company/University:

Swinburne University of Technology

New and emergent ironmaking Technologies I / 61

Thermodynamics and Kinetic Modelling of Flash Reduction Ironmaking

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Flash reduction ironmaking is being developed as an alternative pathway for producing DRI from iron ore fines. Producing DRI directly from fines eliminates pelletising step. Flash reduction in ironmaking was pioneered by Sohn et al. where they used co-current flow of hydrogen at a temperature between 1200 to 1600℃ with iron ore particle size between 20 to 53 μm. Calix is developing Zero Emission Steel Technology (ZESTY), a flash hydrogen direct reduction ironmaking process where

iron ore powder is fed from the top and 100% H2 is introduced from the bottom. The working temperature is between 800 to 1100 ℃ with iron ore particle size < 500 µm. The process employs a vertically oriented reactor with indirect electrical heating, enabling hydrogen to serve solely as a reductant rather than as fuel. The technology has carried out pilot tests with different Australian iron ores and is planning to build a demonstration plant of 30,000-tonne-per-annum in Western Australia. The highest metallisation level of DRI produced from ZESTY pilot test was 98%. Increasing temperature from 900 to 1050℃ and H2/O_reduction ratio from 1.2 to 2 has a positive effect on the level of metallisation. Fayalite (Fe_2SiO_4) formation was observed in DRI produced from goethite/hematite ores. Thermodynamic calculations were undertaken to investigate the formation behaviour of fayalite under ZESTY operating conditions and to assess how ore chemistry and selected additives (e.g. CaO, MgO) influence its stability. These studies support a broader investigation into the role of fayalite in flash hydrogen reduction and its relevance to both metallisation and downstream ironmaking processes. Results showed that adding 10 wt% of CaO to the iron ore reduces the amount of H2 required to reach 100% metallisation level (up to 47%) as CaO can capture SiO2 and preserve FeO for hydrogen reduction. In a separate strategy, calculations predicted that adding 12.5 vol.% CH4 to H2 increased metallisation level from 82% to 97.6%. Kinetic study of ZESTY at 950 °C showed that porosity of the ore and particle size played an important role to the reduction degree of all types of ores. Reduction by 100% H2 was 3 times faster compared to 15% H2. In a separate study of first order kinetic modelling of ZESTY showed that increasing temperature and hydrogen stoichiometric ratio enhanced the level of metallisation. Increasing particle size lowered the metallisation level through decreasing residence time. These findings are consistent with ZESTY pilot plant results.

Speaker Country:

Australia

Speaker Company/University:

Swinburne University of Technology

Process Control and Quality Improvement / 62

Temperature-Dependent Carburization Kinetics and Carbon deposition of iron in CO-H2-CH4 Gas Mixtures

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The global steel industry's transition toward low-carbon ironmaking is driving the expanded utilization of direct reduced iron (DRI) and hot briquetted iron (HBI). During the DRI process, carburization occurs concurrently with iron ore reduction in gas mixtures containing CO-H2-CH4, and it is critical for reducing the melting point of the product, thereby enhancing the energy efficiency and operational stability of subsequent steelmaking operations. Among commercial DRI processes, Energiron and Midrex are the most widely applied. Energiron operates at carburization temperatures above 1273 K, whereas Midrex proceeds at relatively lower temperatures below 1173 K. As a result, the two technologies show clear differences in carburization kinetics arising from variations in temperature, pressure, and gas composition. Accordingly, systematic comparative studies are needed to optimize process time and energy consumption.
This study investigated the carburization kinetics of pure Fe at 1073 K and 1273 K, corresponding to typical Midrex and Energiron carburization conditions, under various CO-H2-CH4 gas compositions, using thermogravimetric analysis (TGA). Carbon/Sulfur analysis and optical microscopy were conducted to determine the carburization behavior and the extent of carbon deposition.
The results demonstrated that the influence of the carbon source on carburization is significantly dependent on temperature. At the low temperature of 1073 K, CH_4 was negligible due to its limited capacity for C-H bond cracking. However, at 1273 K, the surface reaction rate of CH_4 was found to

be more than three times faster than that of CO, indicating that CH_4 is highly effective in enhancing the overall carburization rate. Crucially, CH_4-rich, high-temperature gas compositions were found to cause severe carbon deposition concurrent with rapid carburization kinetics. Tablet-specimen experiments demonstrated that CH_4 conditions induced pronounced structural degradation and significantly accelerated carbon deposition. This behavior is interpreted as a result of excessive carbon precipitation driven by elevated carbon activity, causing internal stress and fragmentation. Furthermore, thin-foil experiments revealed that the extent of carbon deposition is strongly influenced by the initial surface roughness and specific surface area of the Fe substrate. Therefore, while CH_4 is favorable for achieving fast carburization kinetics at high temperature, controlling carbon precipitation and soot formation is essential for ensuring the stability of CH4-based processes.

Speaker Country:

Korea South

Speaker Company/University:

Inha university

Use of alternative iron sources / 63

DRI/SCRAP blending in EAF practice. Impacts on slag composition, energy consumption and furnace productivity

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The net zero emission target for steelmaking is pushing toward the adoption of breakthrough technology. The process route based on iron ore pellets direct reduction requires also a fine tuning of the subsequent melting step in EAF. This, in turn, will require the adoption of modified operating practices, tailored to the EAF input charge of materials.
The blending of DRI and scrap is a way to compensate for the increased energy demand required by DRI melting. The ratio DRI/scrap will depend on the required steel quality, the plant productivity needs, the energy demand, and the quality of input pellets. Anyhow, the adoption of hybrid EAF practices will impact on slag composition & chemistry, because scrap reduces Si, S, P from high-P DRI and lowers slag volume, minimizing limestone/fuel additions.
DRI contains FeO (linked to an endothermic reaction) and gangue (mainly composed by SiO_2). On the other hand, melting requires more electricity and lime, increasing slag and heat loss. As a result, optimal blend approaches require a deeper understanding of the occurring phenomena (e.g foaming, refractory erosion and P removal).
The presented work is based on activities at the EAF pilot plant (7t capacity), installed in the frame of the IPCEI HYDRA project, which offers a testing scenario for such metallurgical challenges induced by DRI use. In particular, the work is focused on the results of pilot trials with variable amounts of scrap/DRI blending (from 100% scrap to 100% DRI). The results analysis is supported both by thermodynamic codes use to describe slag modification and a proprietary EAF model.
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Speaker Country:

Italy

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AI and Machine Learning in Process Optimization II / 64

Hybrid Metallurgical and Machine Learning Model for Temperature Prediction in DRI-Based EAF

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Electric Arc Furnace (EAF) steelmaking is an energy-intensive and highly dynamic process in which accurate bath temperature prediction is essential for stable refining, energy optimization, and minimizing tap-to-tap variability. This study develops a hybrid temperature prediction framework by integrating first-principles metallurgical modeling with machine-learning validation using historical operational data from a DRI-based EAF. A detailed heat-balance model was constructed to capture the major thermochemical interactions governing temperature evolution, incorporating FeO reduction kinetics, carbon dissolution from DRI, slag formation thermodynamics, electrical energy input behavior, oxygen injection effects, and heat losses through off-gas and water-cooled panels. These physics-based calculations provide a mechanistic foundation that reflects the true metallurgical pathways of a DRI-intensive furnace. To enhance predictive accuracy, the physical model was fine-tuned through machine-learning correction using industrial heat datasets. The hybrid model demonstrated strong agreement with measured temperatures, achieving high R^2(0.9) values and low RMSE(12) across validation heats, thereby confirming its reliability under varying operating conditions. The results show that implementing this hybrid framework can reduce temperature deviations, improve energy utilization, and minimize operator-driven corrective actions. Overall, this work demonstrates that combining first-principles metallurgical knowledge with data-driven machine learning provides a practical, scalable approach for real-time temperature prediction and supports digitalized, energy-efficient, and sustainable EAF steelmaking.

Speaker Country:

United Arab Emirates

Speaker Company/University:

EMSTEEL

New and emergent ironmaking Technologies I / 65

HIsarna –smelting reduction for a carbon neutral steel industry

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The HIsarna ironmaking process is a smelting reduction process under development at pilot scale at Tata Steel in IJmuiden, the Netherlands. The pilot trials have reached a stage where upscaling to an industrial scale can take place.
Over the past few years several significant upgrades were made to the pilot facility to improve operational stability and plant reliability to further explore the process window. To support the upscaling effort focus of the most recent trials has been on maximising productivity and widening the raw materials window. Work is also ongoing to minimise the total carbon footprint and achieve carbon neutral hot metal production.
A series of successful trials at high productivity has demonstrated the required process stability and energy efficiency to justify scaling up to an industrial scale plant. The current pilot plant has a name plate annual production capacity of 65 000 tons of hot metal. A first economically viable industrial scale facility would need to increase this with a factor 15 and be able to produce around 1 million tonnes of hot metal per annum.
Besides stable operation and a high productivity it is also important that the process can work with a range of raw materials. Over the past year several ore qualities, including lean ores, as well as coals and alternative carbon sources have been successfully tested.
As the HIsarna process uses pure oxygen instead of hot blast, the process gas consists of a concentrated CO2 stream which is very suitable for CO2 capture. At the same time effort is ongoing to try and fully replace fossil carbon input with sustainable fossil free alternatives.
This paper will discuss the latest results from the pilot plant trials, look at some of the criteria for up scaling and define the carbon footprint according to the LCA method.

Speaker Country:

Netherlands

Speaker Company/University:

Tata Steel IJmuiden

Integration of Renewable Energy & Biochar Applications / 66

Environmental Compliance and Energy Efficiency Strategies for Electric Arc Furnace Steelmaking

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The global transition toward green steelmaking has accelerated the adoption of Electric Arc Furnaces (EAF) in both standalone and integrated steel plants. While EAF technology offers flexibility in raw material use and supports decarbonization goals, its implementation introduces significant environmental and operational challenges. Compliance with increasingly stringent regulations on emissions, noise, and energy efficiency is essential for project viability and access to funding.
EAF operations generate substantial particulate matter, volatile organic compounds, and hazardous pollutants such as SO_x, NO_x, dioxins, and heavy metals. Modern dedusting systems must therefore go beyond conventional designs, incorporating tailor-made solutions for primary and secondary off-gas streams. Advanced gas cleaning concepts include water-cooled ducts, quenching systems, additive injection systems, and pulse jet filters, ensuring compliance with strict emission limits. Fugitive emissions are mitigated through enclosures such as doghouses or elephant houses, combined with optimized canopy suction systems supported by CFD-based design.
Noise emissions from EAF often exceed existing levels of traditional BOF converters, which causes challenges for plants located near metropolitan areas. Solutions include acoustic insulations, strategic layout planning, and structural enclosures. Doghouses not only reduce noise but also improve safety and reduce fugitive emissions. For auxiliary systems such as ID fans and filter plants, noise

cladding and low-speed fan designs further contribute to compliance with authority requirements. A holistic planning of the noise mitigation concepts in the early planning phase of an EAF project is essential.
EAF processes release large amounts of thermal energy, creating opportunities for waste heat recovery. State-of-the-art systems capture off-gas heat to produce steam for on-site networks or district heating, reducing overall energy consumption and supporting sustainability targets. Integration of steam accumulators and hot water storage ensures stable supply despite fluctuating off-gas conditions. These measures not only enhance energy efficiency but also qualify projects for green funding initiatives.
Digital tools, including real-time emission monitoring, dynamic damper control, and optical fume detection, optimize dedusting performance and energy use. Intelligent control algorithms enable precise airflow management, reducing power consumption while maintaining environmental standards.
Through the integration of advanced gas cleaning technologies, comprehensive noise mitigation measures, and waste heat recovery systems, modern EAF installations can achieve compliance with stringent environmental and energy regulations. These measures not only minimize emissions and optimize resource utilization but also enhance operational performance and reduce lifecycle costs. By aligning with regulatory frameworks and sustainability targets, such projects position steel producers to secure green funding opportunities and strengthen their competitiveness.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies

Successful implementation of electric steelmaking technologies & Best practices / 67

The Electric Arc Furnace for next gen mini mill

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In the blooming market of mini mill plants, our latest plant at Hybar, Osceola, Arkansas, has been starting up a 630,000 tpy rebar production since September 2025, setting new benchmarks for productivity, performance, safety and environmental emissions, while fully meeting the requirements of a CMT mini mill. The paper presents latest EAF technologies including the X-Pact® AURA DC power supply, Condoor®, X-Pact® Sampler, SafEBT's equipment as well as the Spray Systems design and their impact on Green steel production

Speaker Country:

Italy

Speaker Company/University:

SMS Group

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 68

Skills for Industrial Symbiosis and Energy Efficiency (Skills4EII)

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The green transition of Europe's energy-intensive industries and especially the steel industry through hydrogen and renewable energy sources as well as through industrial circularity and symbiosis demands technological readiness and systemic upskilling and reskilling. This contribution explores workforce transformation for Europe's energy-intensive industries, focusing on pro-active skills adjustment for industrial symbiosis and energy efficiency.

This presentation shows first results of the social innovation based Skills4EII and SPIRE-SAIS Skills Alliance where the steel sector is prominently engaged. Based on outcomes of the Skills Alliance for Industrial Symbiosis (SPIRE-SAIS) and the skills intelligence tool "Skills4Sight"of Skills4EII skills classification, affected job profiles and game changer profile roles will be presented. This includes outlining the most urgent cross-sectoral and sectoral skills needs and related training approaches (via the online training platforms steelHub, SKILLS4Planet, Hub 5.0). Additionally, the results of the Technology and Skills Radar 2025 for the steel industry are presented. Linked to the green, digital and social transition of the steel industry (and other energy intensive industries) this ensures future-proof skills and prepares the workforce for future challenges.

Skills4EII is a mission-oriented innovation project focusing on Industry 5.0 principles, integrating SPIRE-SAIS and ESSA project to develop a cross-sectoral platform for training and certification,identifying evolving occupational profiles and gaps in existing education offerings.
Based on the results of ESSA and SPIRE-SAIS, supported by the Pact for Skills Large Scale Partnership Energy Intensive Industries LSP EII, Skills4EII is exploring what skills will be needed in the future and offers practical guidance to help energy-intensive industries and especially the steel industry to get their workforce ready for the energy transition and adapt to new challenges.

Speaker Country:

Germany

Speaker Company/University:

TU Dortmund University

Circularity and by-product management in the steel industry / 69

Valorisation of EAF dust by agglomeration and recycling back to process

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Steel industry is a major contributor to the global economy but generates significant amounts of residues. Most are valorised by internal recycling or external use. Significant amounts of carbon and iron units cannot be recycled because the zinc content in the dust and sludge is too high for steelmaking, yet too low and contaminated with impurities to be processed by zinc producers The landfill is a high-impact and high-cost solution, not economically sustainable. For the recycling of these residues in steelmaking processes, the removal of zinc is important since this element creates various problems in steel plants. About 30% of the EAF (electric arc furnace) dust cannot be recycled due to zinc content. The European project ZincVal (RFCS-02-2022-RPJ, 10111263) aims to develop

technologies integrated with the steel production that enable recovery of iron, carbon and zinc from dust and sludge and avoid landfilling. The approach of using different technological routes, at relatively low starting TRL and with synergies between some of the approaches represents a significant and credible due diligence approach to both increasing the valorisation of low zinc-containing residues in current steelmaking practices and preparing for a significant increase in the availability of these in future steelmaking. Based on the properties of dusts and sludges, determined via physical, chemical and mineralogical characterization, the project will design the most sustainable recycling routes for different residues regarding environmental impact, energy consumption and CO2 emissions, as well as cost-effectiveness. The project approach for EAF dust is to test methods and design recipes for producing agglomerates in form of briquettes for recycling back into the EAF to enrich dust in zinc contents above the threshold set by zinc smelters. Experimental campaign conducted on laboratory scale will be presented. The goal of this experimental campaign is to identify the best recipe to produce briquettes that have acceptable mechanical strength and are compatible with melting operations in the electric arc furnace.

Speaker Country:

Italy

Speaker Company/University:

RINA CSM

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 70

HåBiMet –Safe management of sustainable biocarbon for metallurgical use

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Background
The HåBiMet projects (HåBiMet is a Swedish abbreviation for Sustainable Biocarbon for Metallurgical use) originate from a fundamental question: Why is there still no large-scale market for metallurgical biocarbon? Despite its potential to enable fossil-free metal production and deliver significant climate benefits, biocarbon faces critical barriers to industrial adoption. Handling biocarbon introduces safety challenges such as mold growth, self-heating, and spontaneous ignition during storage and transport. These risks compromise material quality, occupational safety, and operational reliability, limiting its integration into metallurgical processes. HåBiMet is a group of projects addressing enablers and barriers for utilizing biocarbon in metallurgy from technical, social, and policy perspectives. This specific project focuses on safe management by reducing risks associated with mold formation and spontaneous combustion.
Objectives
The primary objective is to develop predictive models, guidelines, and best practices for the storage, transportation, and utilization of biocarbon in metallurgical applications. This includes generating knowledge through laboratory experiments, numerical simulations, and industrial trials to identify and minimize risk factors. Additional aims involve characterizing the properties and behavior of biocarbon briquettes to optimize production methods, ensuring mechanical stability and compliance with industry standards. The project also seeks to strengthen technical competence, improve workplace safety, and establish best practices that support sustainability across the supply chain. Furthermore, regulatory frameworks governing biocarbon storage and transport will be examined to ensure alignment with safety and environmental requirements.
Methodology
The research integrates controlled laboratory investigations –such as climate chamber testing, mold growth analysis, and isothermal calorimetry –with advanced computational modeling using CFD

and DEM techniques. Full-scale industrial trials will validate laboratory findings and provide real-world data for model calibration. Risk and occupational safety assessments will complement technical analyses, ensuring that outcomes translate into practical and regulatory-compliant solutions.
Expected results and impact
The project is expected to deliver quantitative data on the interactions between moisture, temperature, and mold formation, as well as kinetic models describing self-heating and spontaneous ignition. These results will inform the development of guidelines and best practices for safe biocarbon handling. In addition, the project will produce recommendations for regulatory compliance and establish a knowledge-sharing platform to facilitate industry-wide adoption. By addressing critical safety challenges, HåBiMet will contribute to a sustainable and resilient biocarbon supply chain, supporting the metallurgical sector's transition to fossil-free production while enhancing operational safety and efficiency.

Speaker Country:

Sweden

Speaker Company/University:

Swerim AB

Integration of Renewable Energy & Biochar Applications / **71**

Modelling of Hydrogen Flame Interaction with the Scrap Beds in Steelmaking Furnaces

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In steelmaking, burners are essential for delivering heat, particularly in Electric Arc Furnaces (EAFs) and Reheat Furnaces (RFs). Within EAFs, despite the majority of heat being supplied through electric arcs, burners provide heat to cold spots to homogenise heat distribution, enhancing overall thermal efficiency and increasing output. Traditionally, these burners rely on carbon-intensive fuels, which exacerbate greenhouse gas emissions and contribute to environmental issues. Hydrogen has emerged as a cleaner substitute, as its combustion yields no carbon dioxide. However, hydrogen's unique flame characteristics result in different heat patterns and transfer rates within the furnaces. A thorough investigation is needed to grasp these effects and ensure safe adoption in steel production. This research specifically examines the heat transfer dynamics of hydrogen flames versus those from carbon-based fuels, while offering mathematical modelling approaches. Findings indicate that, at equivalent burner output, hydrogen flames deliver superior heating in the initial minutes over propane; yet, achieving this requires a substantially higher hydrogen flow rate, resulting in elevated inlet pressures or velocities. Additionally, the study reveals that hydrogen flames penetrate much deeper into the scrap beds due to their elevated speeds and extended lengths.

Speaker Country:

Australia

Speaker Company/University:

Swinburne University of Technology

Poster session / 72

From Scrap to Safety: Low-CO_2 Steels in Automotive Applications

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Steel production accounts for approximately 7–9% of global CO_2 emissions, making it one of the most critical industrial sectors in the transition toward climate neutrality, a strategic objective of the European Union by 2050. To reduce environmental impact, many steelmakers are converting traditional Blast Furnace–Basic Oxygen Furnace (BF–BOF) routes to more sustainable technologies such as the Electric Arc Furnace (EAF), which is primarily based on scrap recycling and supplemented with DRI (Direct Reduced Iron), HBI (Hot Briquetted Iron) and pig iron.
However, increasing the scrap content results in higher concentrations of tramp elements, particularly copper (Cu) and tin (Sn), which can negatively affect steel performance by altering microstructure and reducing formability, weldability and fracture resistance. This challenge is especially relevant for automotive applications, where safety, reliability and lightweighting requirements are extremely demanding.
In this context, the European RFCS project "Safe&Clean", coordinated by EURECAT and involving ten industrial and academic partners, aims to characterize low-CO_2 steel sheets produced through innovative processing routes and compare them with equivalent grades manufactured via conventional BF–BOF production. The experimental work focuses on two advanced high-strength steels for automotive structures: DP780 (provided by Salzgitter) and H550MS (provided by SSAB). These materials will be examined through comprehensive chemical, microstructural and mechanical characterization, as well as functional testing including crashworthiness, fatigue resistance and structural integrity under quasi-static and dynamic loading.
To evaluate real-application behaviour, two demonstrator components will be manufactured by the end-users: a side connector produced in DP780 (CRF) and a lower control arm produced in H550MS (Autotech).
The expected outcomes will support the development of technical guidelines for the industrial adoption of low-CO_2 steels in automotive applications, contributing to the decarbonization of European mobility and promoting a more sustainable and circular steel value chain.
Acknowledgments: We would like to thank the partners of the Safe&Clean project for their contribution

Speaker Country:

Italy

Speaker Company/University:

Università degli Studi di Torino

Automation and Digitalization in Electric Steelmaking II / 74

Thermodynamic Assessment of Metallurgical Processes Using Thermo-Calc and MATLAB Integration

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Accurate prediction of thermodynamic behavior in metallurgical melting processes is essential for optimizing industrial operations and reducing experimental costs. This work introduces a computational tool that integrates the Process Metallurgy module of Thermo-Calc with MATLAB to enable automated, scalable evaluations of multiple process scenarios. Traditionally, performing sequential calculations in Thermo-Calc requires manual input, which is time-consuming and limits efficiency when exploring large parameter spaces. To overcome these limitations, the Thermo-Calc Toolbox for MATLAB was implemented, allowing the development of a custom script capable of processing diverse parameter sets for various thermodynamic conditions.

The initial script was designed to execute multiple calculations in sequence, significantly reducing manual effort. Building upon this foundation, the script was further enhanced and transformed into a MATLAB-based application featuring a graphical user interface (GUI). This application provides an intuitive platform for configuring input parameters, initiating calculations, and visualizing results through customizable plots. The visualization capabilities allow users to quickly interpret trends and compare outcomes across different parameter sets, offering a clear overview of complex thermodynamic relationships.

A key advantage of the developed tool lies in its ability to perform extensive parameter sweeps, enabling rapid recognition of improved conditions for metallurgical processes. Additionally, the application supports preliminary estimations under fixed conditions, which can be benchmarked against experimental data. This functionality assists process engineers in validating theoretical predictions and refining operational strategies prior to costly experimental trials, thereby improving efficiency and sustainability.

The integration of Thermo-Calc with MATLAB through a custom-built application demonstrates how traditional thermodynamic assessments can be transformed into an automated, user-friendly, and highly visual process. By combining automated computation, interactive visualization, and flexible parameter management, this approach provides a robust platform for systematic evaluation of smelting processes. Ultimately, the tool contributes to faster decision-making, reduced development time, and enhanced process reliability in modern metallurgical operations.

Speaker Country:

Austria

Speaker Company/University:

voestalpine BÖHLER Edelstahl GmbH & Co KG

Automation and Digitalization in Electric Steelmaking II / 75

Stability Enhancement of DC Arcs in Reducing Argon-Hydrogen Atmospheres via Current Regulation

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Abstract

This work introduces an innovative method for controlling the stability of direct current (DC) arcs

in reducing argon-hydrogen atmospheres, a key enabler for hydrogen-plasma smelting reduction (HPSR) processes aimed at decarbonizing steelmaking. By dynamically adjusting current, the system maintains robust arc behaviour under challenging conditions, supporting both process reliability and energy efficiency. The approach is based on modelling, integrating insights from detailed simulations and experimental data to optimize arc stability while minimizing hydrogen as well as energy losses and preventing unwanted arc extinction. Experimental validation is carried out on a laboratory-scale HPSR reactor equipped with advanced diagnostic instrumentation.

Power Supply
A high-frequency (50 kHz) pulse-width modulated (PWM) switching current regulator is employed to power the electric arc between a solid plate or melt bath and a hollow graphite electrode. A choke inductor smooths the current. Due to the high switching frequency, the required inductance is much smaller compared to the classical approach of using thyristor rectifiers. The concept is demonstrated at power levels up to 5 kW.

Operation
A mixture of argon-hydrogen gas is injected directly into the reactor through the electrode assembly. This configuration ensures precise control of the plasma environment and promotes efficient hydrogen utilization during iron oxide reduction. High-speed data acquisition systems capture voltage and current waveforms at microsecond resolution, enabling accurate characterization of transient arc phenomena. Synchronized video imaging provides visual insights, while additional sensors monitor temperature and other process variables. These measurements are used to validate simulation models and assess controller performance across a range of operating conditions, including variations in electrode distance, power input, and gas flow rates.

Outlook
The goal is to significantly enhance arc stability in argon-hydrogen atmospheres, reducing fluctuations and improving operational consistency. The integration of real-time measurements with predictive control enables adaptive optimization, ensuring efficient energy use and meeting hydrogen utilization targets. Future work will focus on transferring the system to an existing HPSR pilot plant, paving the way for advanced automation and digitalization in electric steelmaking. This development represents a critical step toward sustainable steel production, combining process innovation with environmental responsibility.

Speaker Country:

Austria

Speaker Company/University:

K1-MET

Ladle metallurgy and slag control / 76

In situ observation of metal-slag separation and inclusion motion at the surface of hydrogen-based direct reduction iron melt

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Hydrogen-based direct reduction is emerging as a promising strategy for steel production due to its low CO2 emissions. In this process, the melting of direct reduced iron (DRI) and the separation of steel and slag occur in the electric arc furnace (EAF). However, this process is affected by the thermophysical properties of slag, which are critical and ultimately affect both the yield and the cleanliness of the produced steel.

This study investigated the effect of various thermophysical properties (such as basicity, viscosity, melting point, etc.) of slag on the steel-slag separation process, utilizing different grades of DRI. The in-situ melting behavior of DRI pellets was observed using high temperature confocal laser scanning microscope (HT-CLSM). Multi-scale characterization techniques were employed to analyze the evolution of the steel and slag at different stages of the melting process. The smelting temperatures for low-grade and high-grade DRI should exceed 1530 ℃ and 1580 ℃, respectively, to ensure optimal melting and separation efficiency. Notably, the uniform distribution of alumina within the slag requires higher smelting temperatures to ensure proper iron-slag separation. This is due to the high melting point of alumina, along with its strong viscosity and surface tension, which hinder the effective separation of steel and slag during smelting, eventually impacting steel purity. Furthermore, non-metallic inclusion motion behavior at the surface of DRI melt is observed by HT-CLSM, and the attraction of different particles are analyzed, the obtained understanding can contribute to the gangue removal and the initial slag formation.

Speaker Country:

Sweden

Speaker Company/University:

Lulea University of Technology

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 77

Targeting and supporting Industrial Symbiosis in the steel industry through the Symbio-Steel project

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Industrial Symbiosis is not a new concept in the steel sector. However, to achieve new opportunities and new synergies, it is crucial to involve other sectors and public authorities, making them aware of Industrial Symbiosis activities already done by the steel industry and the possible barriers hindering synergies and cooperations.
In this context, the project entitled "Fostering Industrial Symbiosis solutions for the steel sector by results monitoring and dissemination from national and EU funded projects coupled to definition of cross-sectorial synergy scenarios"(Symbio-Steel –G.A. No. 101156509), which is funded by the European Research Fund for Coal and Steel (RFCS), aims at analysing the current status, upcoming

techniques, and developments of Industrial Symbiosis implementation, to achieve proactive cross-sectorial cooperation and integrations.
Symbio-Steel contributes to paving the way to uptake Industrial Symbiosis solutions in the steel sector, exploiting and spreading knowledge of the most promising and available results of symbiotic initiatives as well as supporting synergies with other industrial sectors.
By evaluating, promoting and improving existing synergies in Industrial Symbiosis involving the steel industry, Symbio-Steel is aligned with the Strategic Research & Innovation Agenda on decarbonization and resource efficiency, sustainability, and circular economy in the steel production. Symbio-Steel will provide comprehensive guidelines facilitating the transformation of the steel sector towards low-carbon practices. To this aim, gaps between current capabilities and future needs are being identified, fostering collaboration among industry stakeholders, and attracting and recruiting young talents.
During Symbio-Steel, to monitor and assess the impact and the effectiveness of Industrial Symbiosis initiatives involving the steel sector and other energy intensive industries, ad-hoc relevant Key Performance Indicators were defined and selected. They quantitatively sized the progress of Industrial Symbiosis activities in terms of resource efficiency, emission reduction, and cross-sectoral industrial integration. On the other hand, a wide portfolio of technologies and technical solutions developed by the steel industry with other relevant industrial sectors was provided, by revising the main outcomes of relevant regional and EU funded projects. In addition, specific barriers to implementing Industrial Symbiosis practices, including impacts on companies, the environment, and society, as well as different issues affecting networks, were identified. Stakeholders were also consulted through an online survey to identify their perception in terms of demands, opportunity and obstacles concerning Industrial Symbiosis.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna

Recent progress and new developments in CCS/CCU / 78

Pellet porosity changes under simulated blast furnace shaft conditions

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A blast furnace (BF) is still the dominant process for making iron in the world. The blast furnace is charged with coke and iron burden materials including iron ore pellets, sinter and lump ore. While descending in the blast furnace the iron burden reduces. In order to simulate this, two different types of gas-temperature programs have been used. Program (1) has step-wise changes with gas composition consisting of CO, CO2, H2 and N2 whereas in experimental program (2) the changes in gas consisting of CO, CO2, and N2 occur smoothly. Both of these experimental programs are dynamic, and they are developed keeping blast furnace shaft conditions in mind.
In this work two different types of blast furnace pellets were predisposed to the two different gas-temperature programs mentioned earlier. These tests were done for single pellets with a built-in high-temperature thermogravimetric analyzer (TGA). The interest of this work lies in looking at the changes in pellet porosity during reduction. This is done measuring the skeletal volume of the pellet using a Micromeritics Accupyc II 1340 gas displacement pycnometer and combining this with the envelope volume attained by manual pellet diameter measurement in nine directions using a digital slide gauge. Since the interest lies in the pellet porosity, which needs to be measured before

softening and melting, the chosen maximum temperature used was 1100 ℃. It was found out that the porosity of pellet A increased in both experimental programs. The increase was higher (127%) when program (1) was used compared to the pellet subjected to program (2) where the increase was milder (53%). The same trend could be seen in pellet B as well even though pellet B had higher increases in porosities, f. ex. program (2) increase was 102% compared to the grade A increase of 53%.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Renewable gases and CO2 mitigation in steel industry I / 79

Effect of hydrogen oxyfuel combustion on oxide scale descability by thermal shock for low-carbon steels

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Steel industry is in transition concerning heating methods due to requirement to reduce CO2 emissions. Use of hydrogen as a fuel in combustion for heating makes the reheating furnace a possible method to reduce use of fossil fuels. Furthermore, oxyfuel combustion increases efficiency of the heating process compared to air-fuel method. The complete combustion of the fuel is ensured by excess oxidant, providing free oxygen in the furnace atmosphere. Free oxygen content is kept low in industrial reheating furnace to prevent excess oxidation caused material losses. After reheating process, oxide scale formed on the steel surface is removed by water jet descaling to provide clean surface for hot rolling process.
Oxide scale formation of two low carbon steels is investigated in isothermal tests at 1200 ℃ for 2 hours with methane-air and hydrogen-oxygen combustion atmospheres using free oxygen contents of 1% and 6%. Both steels contained silicon, but steel A had higher amount of manganese and steel B had higher amount of chromium and nickel. Descaling efficiency of oxidized samples is studied by thermal shock, dipping the hot sample in water vessel straight from the furnace. Characterization for oxidized and descaled cross-sections of samples was performed by digital microscopy and field-emission scanning electron microscopy (FESEM).
Steel B produces less oxide scale in all studied atmospheres. Hydrogen combustion simulations produce more oxide scale compared to methane due to higher water vapor content, increasing oxidation. Higher free oxygen content has increasing effect on amount of oxide scale and outer layer of oxide scale changes from sharp shaped wüstite to levelled magnetite on the top of the wüstite layer.
Hydrogen combustion simulations decrease the amount of oxide scale detached from the sample for both steels. Surface layer of oxide scale from methane-air with 1% O2 simulations was weak and its fall off by small pieces, while hydrogen-oxygen with 1% O2 had stronger surface layer. Although Steel B was less oxidized, its descalability was weaker compared to Steel A. After hydrogen-oxygen heating with both O2 contents, descaling caused only cracking inside the oxide scale without any part of oxide totally detached out for Steel B, while part of the oxide scale detached out from the sample for Steel A. Thus, increase of water vapor based on hydrogen fuel and oxyfuel method, and oxygen content of furnace atmosphere influence formed oxide scale and its strength against thermal shock.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Safety and Training I / 80

Development of Intelligent Monitoring Systems for Anomaly Detection in Electric Arc Furnace Steelmaking

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The steel industry's transition toward intelligent manufacturing requires sophisticated monitoring systems capable of detecting operational anomalies in real-time. This study presents the development and implementation of Artificial Intelligence-based predictive models for automated anomaly detection in Electric Arc Furnace operations, conducted within the project entitled "Remote expert virtual system enhancing human management capabilities that favors preservation, transfer, and continuous evolution of knowledge for steelmaking operations"(Ref. iSteelExpert, Grant Agreement No. 101112102) , which is co-funded by the Research Fund for Coal and Steel of the European Union.
A comprehensive dataset was collected during normal production operations at an industrial facility. The dataset integrated heterogeneous data sources including chemical composition measurements, operational parameters, and electrical signals. Operator-reported anomalies were systematically annotated, with some heats exhibiting abnormal events across eight distinct categories, including electrodes breakage, roof closing troubles, high-carbon melts, and strong furnace reactions. Several machine learning algorithms were evaluated including Random Forest, XGBoost, Histogram Gradient Boosting, Support Vector Machine, and AdaBoost. The experimental framework encompassed two complementary objectives: generic anomaly detection (identifying any abnormal heat) and specific anomaly classification (distinguishing between different anomaly types). Extensive hyperparameter optimization was performed to maximize detection capability while maintaining acceptable precision. For generic anomaly detection, the models demonstrated robust performance with balanced accuracy exceeding 80% and high detection rates. Specific anomaly classification proved more challenging due to severe class imbalance. Strategic undersampling approaches dramatically improved detection rates for most anomaly types, though requiring careful consideration of the precision-recall trade-off based on anomaly severity.
A proof-of-concept decision support system was developed, integrating genetic algorithms with trained predictive models to suggest corrective process adjustments when anomalies are predicted. The optimization framework balances avoiding alarms with minimizing deviation from current operating conditions while respecting physical and safety constraints. This represents a novel approach combining near real-time ML predictions with actionable operational recommendations in Electric Arc Furnace steelmaking. The findings demonstrate that AI-driven monitoring systems can effectively detect process deviations, particularly for subtle anomalies difficult for operators to consistently identify. Future development will focus on advanced techniques for imbalanced classification to further optimize detection capability across all anomaly categories, ultimately delivering a practical and reliable monitoring solution for Electric Arc Furnace operations.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna

AI and Machine Learning in Process Optimization II / 81

Automated Noise Source Identification in Steel Plants Using Deep Learning

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Steelmaking facilities are significant sources of environmental noise pollution, with complex acoustic emissions arising from diverse operations including Electric Arc Furnace (EAF) melting, hot rolling, scrap handling, and material transport. Effectively managing and reducing industrial noise emissions requires identifying which specific processes and equipment mostly contribute to elevated noise levels affecting surrounding communities. However, continuous monitoring systems deployed in modern steel plants generate vast quantities of acoustic data that make manual analysis and classification impractical, creating an urgent need for automated solutions.

This study presents an intelligent noise monitoring system developed within the project entitled: "Real-time acoustic sensorS and artificial Intelligence appLications for the rEduction of local eNvironmental impaCt due to noise Emissions"(SILENCE) co-funded by Research Fund for Coal and Steel (RFCS). The system is designed to automatically identify and categorize noise sources in operational steel plants without requiring manual labeling of acoustic events. The system utilizes strategically positioned microphones across critical production zones including the hot rolling mill, EAF area, coiling stations, scrapyard, and transport routes to continuously capture acoustic emissions triggered when sound levels exceed predefined thresholds.

The core innovation lies in applying advanced unsupervised machine learning techniques to automatically group similar acoustic events and identify their operational sources. The approach combines Variational Autoencoders with Gaussian Mixture Models to learn characteristic acoustic signatures directly from recorded sound data, represented as Mel-spectrograms that capture frequency and temporal patterns. This methodology enables the system to discover natural groupings in complex, overlapping industrial soundscapes without prior knowledge of event categories.

Comprehensive evaluation demonstrates that this deep learning framework significantly outperforms conventional clustering methods. The system achieves superior separation and identification of distinct acoustic events, with quantitative metrics showing improvements compared to traditional approaches. Testing on both industrial steel plant recordings and benchmark urban sound datasets confirms the robustness and generalizability of the methodology.

The practical implications for steel producers are substantial. Plant operators gain automated tools to pinpoint specific processes responsible for noise complaints, enabling targeted mitigation measures. The continuous monitoring capability supports compliance with environmental regulations by providing objective documentation of noise sources and their temporal patterns. Furthermore, the system's unsupervised nature eliminates the need for extensive expert annotation, allowing rapid deployment across different facilities and operational contexts.

This work represents a significant advancement toward sustainable steelmaking operations, providing an efficient, scalable, and automated solution for industrial noise management that balances production efficiency with environmental responsibility and community relations.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna

Ladle metallurgy and slag control / 82

Development process of the EAF produciton route with new slag management for high silicon steel grade (54SiCr6) for automobile spring steel and low carbon grades (SG2-SG3) for welding wire, from scrap yard to wire rod coil. Lesson learned and future improvements.

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It is known that the steel industry is evolving towards production methods aiming at efficiency improvement and reduction of the environmental impact. It follows that a transition from blast furnace production towards the electric furnace route has been underway for some time now, and it is therefore possible that users of this kind of steel will have to rely on new suppliers with EAF route.
The paper describes the positive experience made by ABS (Acciaierie Bertoli Safau), EAF based steel producer, during the development of the whole manufacturing process of steel grades historically produced through blast furnace route, such as high silicon grade 54SiCr6 for automobile suspensions springs and low carbon grades SG2 and SG3 for welding wire application.
The evolution of this learning path is presented, with focus on the implemented aspects either in the primary and secondary metallurgy and in the downstream processes (i.e. scrap and raw materials, process parameters, slag modification and control, equipment availability, production scheduling) that proved to be fundamental for the achievement of the final product requirements (i.e. steel chemical composition, microinclusion morphology and quantity, blooms and wire rod internal and surface quality, mechanical properties of the wire).
The satisfactory feedback from product performances confirms the effectiveness of this development path and opens to future improvements that can be extended also to other steel grades.

Speaker Country:

Italy

Speaker Company/University:

Acciaierie Bertoli Safau

Automation and Digitalization in Electric Steelmaking III / 83

Leveraging Optical Emission Spectroscopy (OES) for Enhanced Process Control in Ladle Furnace (LF)

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The Ladle Furnace (LF) serves as a secondary metallurgical process unit for adjusting the composition and temperature of molten steel for casting. Changes and transformations in the steel industry—such as green steel and digitalization—emphasize the need for real-time process control and enabling measurement solutions. This work aimed to study how optical emission spectroscopy (OES) data can be used in process control of ladle furnaces. To this end, data from industrial ladle furnaces was

employed to analyze and quantify changes of slag composition continuously and in real time.
The results show that OES can be used to provide real-time data about the chemical composition of slag in ladle furnaces and thus allowing timely process control. Finally, some special benefits of using OES in steelmaking are discussed, specifically, the ability to measure the slag chemical composition in the Ladle Furnace in real-time. OES can yield such information that is not possible or practical to acquire using traditional methods during the process. This cultivates several important use cases and helps operators make accurate decisions.

Speaker Country:

Finland

Speaker Company/University:

Luxmet Ltd

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 84

Metallurgical biocarbon as a decarbonization strategy: Policy drivers and industrial implications from a Swedish perspective

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In Sweden, the transition toward fossil-free metallurgy increasingly considers biocarbon produced from sustainable biomass as a substitute for fossil coal in high-temperature processes such as electric arc furnaces (EAF), tunnel kilns (TK), and submerged arc furnaces (SAF). This study, part of the HåBiMet –Policy Perspective project, examines how EU and Swedish policy frameworks shape the feasibility and competitiveness of metallurgical biocarbon deployment.
The analysis combines desk research with stakeholder workshops and interviews, mapping climate and energy policies (EU ETS, ETS2, CBAM), biomass governance (RED III, LULUCF, EUDR), and environmental regulations (IED 2.0, Miljöbalken i.e. the Swedish Environmental Code). Findings indicate that while there are economic incentives for substituting fossil carbon, such as by zero-rating biogenic CO2 emissions under the ETS and pricing direct emissions of imported iron and steel products under CBAM –other frameworks introduce constraints. RED III's cascading use principle prioritizes wood for material applications over energy, potentially limiting access to forestry residues critical for biocarbon production. IMO transport safety rules and REACH compliance add logistical complexity, while the absence of harmonized standards for metallurgical biocarbon creates uncertainty for procurement and quality assurance. Furthermore, biocarbon expands the intertwining of the metal industry with sectors such as forestry, agriculture and energy, contributing to further complexity.
From an industrial perspective, technical feasibility is established: biocarbon can replace fossil reductants in blast furnace (BF) injection, EAF carburization, and SAF operations. However, cost remains a major barrier –biocarbon is up to four times more expensive than fossil carbon carriers. Policy-driven carbon pricing partially offsets this gap; for example, ETS allowance prices (€70–75/t CO_2) significantly increase the effective cost of fossil coke. Yet, permitting under IED 2.0 and Miljöbalken may raise CAPEX/OPEX for pyrolysis plants, requiring strategic planning and early engagement with regulators.
The study concludes that metallurgical biocarbon will play a transitional role alongside hydrogen-based DRI and CCUS. Although, the surrounding policy landscape is characterized by a lack of clear standards and uncertainty regarding how imminent EU legislation will affect costs tied to different parts of the value chain. To accelerate adoption, industry needs predictable policy signals, clear sustainability criteria, and standards for metallurgical biocarbon quality that are recognized at the EU level. These would advantageously be pursued in collaboration with stakeholders from other sectors to mitigate future conflicts of interest.

Speaker Country:

Sweden

Speaker Company/University:

Swerim AB

Slag control and refractories II / 85

Tenova's Dry-Granulation System for Ladle Furnace Slag (Slag2Build Project)

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Ladle Furnace Slag (LFS) remains one of the least valorised metallurgical by-products in the European steel sector due to its unfavorable mineralogical structure generated by slow air cooling. This conventional Best Available Technique (BAT) produces γ-dicalcium silicate, leading to high dusting rates, significant water consumption, and limited external reuse. To address this bottleneck, Tenova has engineered and patented (EP4100551A1) a forced-air dry granulation technology that thermally stabilizes LFS into a hydraulically active β-C_2S-rich granulate, enabling its use in construction materials. Within the EU project Slag2Build, Tenova's role focuses on the design, scale-up, and industrial integration of this technology into a full-scale demonstrator at the Stomana steel plant.
The purpose of this work is to demonstrate that Tenova's granulation process can achieve TRL8 industrial operation, reaching a continuous throughput and providing a stable, quality-controlled granulated product suitable for downstream applications (plasters, mortars, hydraulic binders).
The technical framework is based on high-momentum forced-air impingement, where a controlled air jet intersects the liquid LFS stream during pouring. Rapid quenching suppresses γ-C_2S formation and preserves β-C_2S, while simultaneously eliminating water use, reducing sulphur-rich fumes, and preventing dust formation. The system integrates thermos-fluid dynamic design principles, slag rheology modeling, heat-transfer analysis, mechanical design, and process control algorithms to ensure consistent granule morphology and temperature regimes.
The methodology for the basic and detailed engineering of the key components of the dry-granulation system requires an extensive programme of computational modelling. The present work reported the results from CFD simulations are employed to characterise the multi-phase interaction between the pressurised air jets and the molten slag stream, to analyse the associated thermal gradients and solidification kinetics, and to predict particle residence times and resulting granulometry. The numerical models developed by Tenova are subsequently validated through experimental campaigns conducted at the pilot-scale granulation facility installed at RINA-CSM (Rome), where controlled trials on representative ladle furnace slag enable direct comparison between simulated and observed granulation behaviour. Full slag characterization before and after the granulation pilot test is performed.

This research is conducted within the framework of the Slag2Build project (RFCS –GA 101193261)"

Speaker Country:

Italy

Speaker Company/University:

Tenova

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 87

Use of alternative carbon bearing materials in electric arc furnace: potential for multiple industrial symbiosis and process integration solutions

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In order to improve the sustainability of scrap-based steelmaking and making this route less dependent on fossil carbon markets, the replacement of anthracite and fossil foaming carbon with alternative carbon bearing materials is a promising solution. Different materials can be considered for this purpose, such as biomass, biochar, plastics and tires. All these materials are generally by-products or wastes of other sectors. Therefore, their use represents an implementation of the industrial symbiosis concept and allows electric steelmaking to further increase its contribution to the implementation of circular economy in the steel sector. However, the feasibility of the usage of these alternative carbon bearing materials depends on their availability and on their features and effects on the process. Therefore, analyses, simulation with dedicated EAF flowsheet model, and industrial trials have been performed during the Horizon Europe project entitled "Gradual Integration of Renewable non-fossil energy sources and modular heating technologies in EAF for progressive CO2 decrease"(GreenHeatEAF –G.A. No. 101092328)". Availability of alternative carbon sources has been explored, simulations on the effects on process and products have been performed and industrial trials have been carried out to explore foaming effects and safety aspects. Generally, together with significant reduction of fossil CO2 emissions, no significant negative effects have been observed with the simulated alternative carbon-bearing materials. However, industrial trials carried out without changes of standard injection systems showed limits for some of them in terms of safety and slag foaming.
Further simulations have been also carried out in process integration contexts to extend the availability of suitable alternative carbon sources. In particular, biomass upgrading is explored by investigating the possibility of recovering part of the electric steelworks available waste heat for this kind of processes. To this aim, EAF flowsheet model has been coupled with two flowsheet models related to biomass pyrolysis and torrefaction.
The contribution focuses on the main results of the listed investigations and provides main barriers and facilitators that can pave the way to these multiple industrial symbiosis solutions.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna - TeCIP Institute - ICT-COISP

Waste Management & Environmental Compliance / 88

Experimental Assessment of Granulated EAF Slag for blasting operations as sand substitute in steel production

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The decarbonization of the steel industry is accelerating the transition toward production routes such as direct reduced iron (DRI), hot briquetted iron (HBI), hydrogen plasma smelting reduction (HPSR), and electric smelting technologies. As a consequence, the volume and typology of electric arc furnace (EAF) slags generated across the steelmaking chain are expected to increase significantly. Identifying high-value reuse pathways for these by-products is therefore essential to support circular-material strategies and reduce the environmental burden associated with primary raw material consumption. This study investigates the technical feasibility of employing granulated EAF slag as a substitute for blast sand in mechanical descaling operations for steel products.
A systematic characterization of 3 granulated EAF slag samples was conducted to establish their mechanical and physical suitability for abrasive blasting. The evaluation encompassed hardness, crushability, stiffness, bulk density, granulometric distribution, and morphological features obtained through optical and scanning electron microscopy. These properties were benchmarked against industrial sand commonly used in descaling processes. Based on this screening, a preliminary slag formulation exhibiting the most favorable hardness–fracture resistance balance is selected for experimental validation.
Blasting trials were performed using a controlled air-jet apparatus designed to propel abrasive particles onto carbon-steel plates of two grades representative of hot-rolled product surfaces. Test conditions varied in abrasive composition (sand, slag, and slag–sand blends), particle size classes, carrier air flow rate, and initial scale layer thickness. The thermal response of the metallic substrate during blasting was also monitored to assess potential process-induced heating. Post-treatment surfaces were examined using scanning electron microscopy (SEM), profilometry, and comparative image analysis to quantify scale removal efficiency, surface roughness evolution, and morphology of the residual oxide layer.
This research is conducted within the framework of the InSGeP project (RFCS –GA 101112665)

Speaker Country:

Italy

Speaker Company/University:

Rina Consulting - Centro Sviluppo Materiali

Recycling, circular economy and reduction of environmental impact in steelmaking I / 89

Industrial evaluation of biogenic secondary carbon carriers in electric arc furnace steelmaking: the BioReSTEEL approach

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The decarbonisation of Electric Arc Furnace (EAF) steelmaking requires the progressive substitution of fossil-based carbon with renewable, biogenic alternatives able to guarantee adequate melting performance, slag foaming behaviour, and process stability. The RFCS project BioReSteel addresses this challenge by developing and validating new biogenic Secondary Carbon Carriers (SCCs), with a specific focus on their industrial implementation in EAF operations.
In this context, to assess the technical feasibility and performance of innovative biochar-based briquettes, characterisation of the materials and experimental campaign have been accomplished. The briquettes were engineered using a 70:30 biochar-to-polymer ratio. In these briquettes the biochar provides renewable carbon for slag foaming and energy input, whereas the polymer is both the biding agent and the component that supports the foam during the melting phase. These effects contribute to the slag stabilisation and improve the thermal protection of the electrodes. In addition, the polymer has a fundamental deoxidizer role since it can release carbon and reductant gases during the pyrolysis at high temperature. In effect, carbon and gases react with the oxides present in the slag, such as FeO and MnO, favoring their reduction and increasing the metallic yield, with advantages in term of energetic efficiency and sustainability of the process.
A multi-scale experimental plan has been established.
1. Laboratory-scale tests included physical-chemical and thermogravimetric analysis, reduction behaviour, melting tests in controlled atmospheres, and preliminary assessment of foaming potential.
2. Pilot-scale experiments carried out to simulate injection/melting dynamics more closely and to refine briquette formulations and feeding strategies.
3. Industrial EAF trials at ORI Martin facilities that validated the optimised materials under real operating conditions, evaluating their impact on:
• slag foaming effectiveness and stability,
• electrical energy consumption and arc stability,
• carbon yield and off-gas behaviour,
• operational robustness and repeatability.
This integrated approach provided a comprehensive assessment of biogenic SCCs as practical substitutes for fossil coal in industrial EAF operations. The outcomes supported the roadmap for large-scale deployment of renewable carbon materials in electric steelmaking, contributing to the EU's strategic objectives for climate neutrality and circular economy.
These activities have been carried out in the frame of Research Fund for Coal and Steel within the RFCS project n. 101112383: "Valorization of wet biomass residues for sustainable steel production with efficient nutrient recycling –BioReSteel".

Speaker Country:

Italy

Speaker Company/University:

RINA Consulting - Centro Sviluppo Materiali

Automation and Digitalization in Electric Steelmaking I / 90

Hot Heel estimation: How system dynamics can be used for multiple purposes

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The present work will show a technique for assessing the amount of hot heel or liquid heel using robust hardware. Additionally: the same data stream used for assessing the Hot Heel, can be used for looking at the integrity of a part of the EAF itself.

Many people still operate by the principle: 1 sensor to track 1 problem or 1 property. This sometimes needs to be adhered to strictly, but often one can do much more using the same data stream. Also: most people have a tendency to try and measure the property they are interested in. Very often this comes with challenges, such as high temperature, or irradiation, as encountered often in the steel industry.
The present paper provides an illustration of both principles.
The main topic is using accelerometer data for assessing the amount of hot heel in an electric arc furnace, relying on liquid dynamics inside the vessel after tilting movement. This offers the operator a tool to further optimize the energy consumption of the EAF.
Secondary to that the same data stream is used to track the integrity of the rocking movement and the components involved as well as the stability of the overall system. This allows the teams to see structural issues coming much ahead of time, and thus prevent larger damage (and costly repairs), or even sudden stops of the EAF.

Speaker Country:

Belgium

Speaker Company/University:

Zensor

Successful implementation of electric steelmaking technologies & Best practices / 91

Coupling innovative sensors, process modelling and data analysis for the improvement of EAF performances and sustainability of steel production for Acciaierie di Calvisano

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The necessity to improve the EAF process performances and its sustainability are becoming more and more relevant id last years for several reasons.
In fact the increase of steel production rates through EAF instead of BF enlarging the application of EAF to further steel grades and the necessity to apply the EAF process also with lower quality scraps both increase the impact of EAF technology development in terms of Industrial results (productivity, metallic yield, costs) and of environmental Impacts (energy/materials efficiency and CO2 emissions) at EU level.
Furthermore the evidence that the reduction of CO2 emissions by EAF is affected strongly by reduction of energy consumption and by increasing of metallic yield, the opportunities offered by the flexibility of EAF process management that enable the possibility to apply new control rules evaluating in real time their benefits, the availability of new technologies and new materials for additions in EAF enable the necessity to take into account new chemical scenarios and new management procedures for process improvements.
With this scope to support the process management it has been realized a great effort to enable the

application of new devices and new sensors to make available new measurement principles to cover part of the missing data during the process.
In parallel in last decades several steps have been realized in terms of process modelling and calculation capabilities in order to have a better representation in off-line mode (predictive modelling) and in on-line mode (real time digital twin) in order to have a technological monitoring of the unknown and not measurable parameters as temperatures, compositions, quantities of steel and slags during the process to complete the whole representations of the process supporting the technologists and operators.
Acciaierie di Calvisano has realized the coupling of these items, modelling and sensors developments, in order to improve capabilities of process management and thanks to this it have been developed specific new control rules devoted to represent specific technological phenomena to be controlled as key aspects to reach the goal of process improvement.
These aactivities of Acciaierie di Calvisano are described as realized also in R&D projects as MultisensEAF and islag with the support of R&D partners and thanks to the increase of internal skills about capability of process modelling and control.

Speaker Country:

Italy

Speaker Company/University:

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Safety and Training I / 92

Next-Generation Workforce Training for Electric Arc Furnace Steelmaking

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Abstract:
The growing digitalization of Electric Arc Furnace (EAF) steelmaking demands a workforce capable of operating increasingly complex and highly automated plants. Traditional training methods —shadowing, manuals, and classroom-based onboarding—are no longer sufficient to ensure consistent operational performance, safety, and rapid adaptation to new technologies. Within the EU iSteel-Expert project, we are developing an integrated, AI-enhanced training ecosystem aimed at accelerating the learning curve of new operators, reducing human error, and supporting continuous upskilling.
The proposed ecosystem combines three complementary components:
(1) NotebookLM-style knowledge environments, structured around validated technical documents, safety rules, and plant-specific best practices. These systems enable trainees to query complex information using natural language, facilitating rapid acquisition of process knowledge and reducing dependency on tacit or undocumented expertise.
(2) Cognitive agents based on the CLEAR architecture, designed to emulate expert operator reasoning, attention management and decision-making under stress or uncertainty. These agents serve as "virtual mentors"capable of demonstrating correct action sequences, highlighting risks, and explaining the rationale behind operational choices.
(3) A domain-specific training chatbot, deployed as an always-available conversational assistant for new employees. The system provides step-by-step support for operational procedures, contextual explanations for alarms and process deviations, and interactive quizzes to reinforce learning.
The training architecture is been designed to integrate seamlessly with existing simulators and digital twins developed elsewhere in the project, providing a cognitive layer oriented toward human learning rather than process modelling. Early evaluations indicate the potential to reduce onboarding time, decrease procedural errors in simulated scenarios, and improve retention of complex operational concepts compared with conventional methods.

In addition to supporting new operators, the proposal enables continuous development for experienced personnel through scenario-based training, "what-if"exercises guided by cognitive agents, and automated feedback based on decision sequences. The approach also enhances safety by reinforcing correct responses to abnormal or hazardous operating conditions.
This contribution presents how AI-driven tools, cognitive modelling and structured knowledge platforms can modernize workforce development in EAF steelmaking, addressing a critical need identified by industry stakeholders and aligning with the strategic objectives of EEC-EMECR 2026.
Preferred Topics:
7 –Safety and Workforce Development
1 –Technological Advancements (AI, cognitive architectures)
2 –Process Optimization (human-factor-driven variability reduction)

Speaker Country:

Spain

Speaker Company/University:

University of La Rioja (Spain)

Use of alternative iron sources / 93

Value chain efficiency analysis of HBI and NH3 to transport green iron for EAF charging

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Green steel requires massive investments into new decarbonized production technology and green energy supply, yet renewables are cheapest to produce in remote locations far from established steel production sites. Is it thus more sensible to relocate the energy intensive iron production step near renewable energy, or should investments aim at bringing green energy efficiently to the existing sites, such as with green ammonia (NH3)? A full value chain analysis is conducted to answer this question, accounting for process losses, yield losses, and other impactful details, which may not be obvious to the naked eye in an oversimplified first assessment.

Speaker Country:

Luxembourg

Speaker Company/University:

SMS Group

Automation and Digitalization in Electric Steelmaking III / 94

New approaches for CO2 emissions reduction and process performances improvement in EAF thanks to application of deep process modelling and control to scrap melting and slag foaming

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The technologies related to EAF steelmaking have continuous developments aiming the improvement of the process performances and of the environmental impact mainly through the reduction of energy consumption, the increase of productivity, the increase of metallic yield and promoting the reduction of CO2 emissions.
These improvements pass strongly by improved capability to monitor and control the scrap melting evolution and thanks to capability to evaluate the effect of new injected materials in terms of slag foaming but these aspects are not evident with the typical system available on -site.
In particular to monitor both aspects it is necessary to understand the evolution of the whole process and reacting volume in terms of components, energies involved, undesired effects on the plant.
For this reason all informations available have to be collected in a whole view and representation in order to derive the evidences of phenomena behavior and suggesting control action related to them.
For this reason Feralpi Siderurgica has strongly worked in the development of these aspects with internal skill also with its own EAF on-line dynamic process modelling approach in order to make evident the status of the process in each moment and to be able to better understand the technological results of the management actions.
These are the preconditions for the subsequent improvement of the control rules to be applied.
In last years also thanks to the R&D projects activities Feralpi has realized several steps in the different sites related to the applications of mathematical modelling for EAF processes prediction, process modelling of steel treatment in LF enabling also steel temperature management and scrap melting rate predictions.
Further steps of this development included the real time prediction model in EAF, the application of alert functions for abnormal energies distribution or chemical injections as related to correctness of steel temperatures as support to production management.
The applications realized in different R&D projects are reported including the coupling with plants and sensors development necessary to support the process control.

Speaker Country:

Italy

Speaker Company/University:

Feralpi Siderurgica

Process Control and Quality Improvement / 95

Dynamic Modeling and Optimization of Electric Arc Furnace Operation: Coupling Energy, Oxygen, and Slag Chemistry

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Electric Arc Furnace (EAF) steelmaking is increasingly central to modern steel production due to its ability to operate with low-carbon feedstocks and flexible charging strategies, yet its behaviour is far from steady-state. Energy input, oxygen lancing, carbon for slag foaming, flux additions, continuous slag removal and semi-continuous charging interact throughout the heat, making the process

highly dynamic. Conventional KPIs capture these variables individually, but they do not explain how changes in one input propagate through temperature, FeO formation, basicity development or tap-to-tap performance. This work focuses on bridging that gap through the development of a dynamic, data-supported model that links furnace inputs to thermal and slag-phase outcomes using real industrial evidence.
The objective of this work is to understand how oxygen and carbon injection, flux additions, and energy input from electrical arcs and chemical reactions influence temperature development and slag behaviour during the heat. To achieve this, 100 consecutive heats from a semi-continuous EAF were analysed. The dataset includes electrical and chemical energy input, carbon and oxygen injection rates, charge and flux additions, as well as measured temperature readings through the heat. Slag samples provide FeO, P2O5 and CaO-SiO2 data for benchmarking the model against industrial behaviour. Temperature evolution is modelled using mass and energy balance principles, accounting for electrical heat input, chemical reactions and heat losses. A parallel slag-reaction module tracks FeO formation and basicity change as a function of time-varying oxygen and flux practice.
Preliminary results show that the model captures overall temperature progression with reasonable agreement to plant measurements, and input-output correlations indicate that oxygen and carbon practice influence slag chemistry and thermal rise. CaO and FeO trends follow expected dephosphorisation behaviour, and variations in slag removal during the heat are reflected more accurately when linked to CO generation signals rather than assumed to be constant. These relationships form the basis for identifying where operational decisions have the strongest downstream impact, without yet claiming full predictive optimisation.
This work contributes a physically grounded modelling approach that clarifies how furnace practice drives slag evolution and temperature response in semi-continuous EAF operation. The results establish the modelling foundation upon which future optimisation, control logic and simulation studies can be developed as more heats and slag data become available.
Keywords: Electric Arc Furnace, dynamic modelling, oxygen efficiency, slag chemistry, energy optimization, semi-continuous operation, industrial validation.

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

Slag control and refractories II / 96

Future slags in electric-based ironmaking and steelmaking

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Ironmaking and steelmaking decarbonization involves significant transformations in existing production processes, and electric-based melting units are acquiring even more importance. Both Electric Arc Furnace (EAF) and Electric Smelting Furnace (ESF) are indeed considered at the bases of future steel and hot metal production, respectively. EAF is a well-known technology deeply used in scrap-based steelmaking and that, in future, will be included in novel integrated steelmaking route coupled with shaft furnaces for iron direct reduction. ESF is a technology used also in other metallurgical sectors, while it is now receiving ever increasing attention also in the steelmaking field.
Since the availability and quality of raw materials (e.g. scraps) is affected by emerging countries and

markets, Direct Reduced Iron (DRI) and Hot Briquetted Iron (HBI) are expected to be exploited more in both processes. DRI and HBI availability and quality will be affected by the pellet, strongly linked to the raw material quality, and gas mixture used in related production. Besides process changes and adaptations requirements, to achieve product specifications and sustainable processes, also slag modifications have to be explored for ensuring one of the pillars of ironmaking and steelmaking: its role in circular economy thanks to its main byproduct (i.e. the slags).
The contribution focuses on scenarios investigations carried out with two flowsheet models (i.e. for EAF and ESF) and during the European project entitled "Investigations of Slags from Next Generation Steel Making Processes"(Ref. InSGeP), Grant Agreement No. 101112665. The EAF flowsheet model is a part of a complex stationary model covering the whole scrap-based electric steelmaking. It was firstly developed for making energy and environmental impact evaluations, was then adapted to carry out different types of investigations, and it was validated for different steelworks and steel families. The ESF stationary model has been recently developed based on literature results. It considers ESF in a modular way by reproducing main ESF phenomena and reactions. Different zones are considered to this aim, namely charge zone, top ESF zone, bottom ESF zone and discharge zone. Simulations have been performed via the mentioned models under certain product and process specifications. They allowed exploring, among other aspects, the amount and chemical composition of slags produced with different iron bearing materials fed alone or in mixture. The results show interesting behaviors. The effect severity reflects the quality of used material, and process adaptations are sometimes required to make the slags suitable for correct industrial operations.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna - TeCIP Institute - ICT-COISP

Innovations in EAF Technology I / 97

Direct Feed to Enhance Power Quality and EAF performance

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Decarbonizing steelmaking is one of the greatest challenges of the steel industry. Electrifying steel production—particularly through the deployment of Electric Arc Furnaces (EAF)—is a pivotal step in reducing CO_2 emissions. In the coming years, the installed base of high-power EAF is expected to expand significantly, notably as replacements for traditional blast furnaces. This rapid growth brings major challenges in terms of energy consumption, productivity, and operational expenditure (OPEX) to maintain or improve current performance levels. Because an EAF represents a large, highly dynamic electrical load, its expansion places additional stress on electrical networks. This situation is further amplified by the massive integration of renewable energy sources, whose variability increases the complexity of maintaining grid stability. As a result, ensuring both power quality and high EAF performance is becoming increasingly challenging.
To address these challenges, GE Vernova has developed an innovative solution: the Direct Feed system. This technology enables a strong decoupling between the EAF and the grid and enables precise, and provides precise, highly stable electrode-current regulation. The description of the technology and the last innovation is presented in a separate EEC 2026 conference paper titled "Next Generation Direct Feed MV Power Supply for Large Steelmaking EAFs". This paper focuses on Direct Feed impact on both power quality and EAF performance. Results obtained from simulations and onsite measurements will be presented. Key outcomes—including significant improvements in flicker reduction and overall EAF operational performance—will be highlighted.

Speaker Country:

France

Speaker Company/University:

GE Vernova

Slag control and refractories I / 98

Slag Management: The Most Under- and Over-Estimated Success Factor in EAF Steelmaking

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Make the slag, and the steel makes itself. This expression underlines a central idea in electric arc furnace (EAF) steelmaking: slag is a key part of the process, even if it is not part of the product. "Good"slag influences energy consumption, refining quality, and overall process stability. However, recent findings strengthen the impression that today's slag analysis methods often do not match the importance of slag itself.

Most steel plants analyse slag as pressed pellets using X-ray fluorescence (XRF). While this method works well for many laboratory samples, it has clear limitations when applied to granular, non-homogeneous slag. XRF also has known analytical challenges for light elements such as Si, Mg, and Al. These weaknesses become visible when different laboratories analyse the same material.

A recent round-robin test with granular slag samples revealed substantial differences between laboratories, especially for key oxides. For example, one laboratory reported 39.8% Al_2O_3, while another measured 35.8% Al_2O_3 (outliers already removed) for the same sample. This raises an important question: How can a slag engineer make reliable process decisions when analytical results vary this much? The round-robin results show clearly that the default method is not always precise enough for robust process control—especially when decisions based on these results can easily cost thousands of euros per heat and millions per year.

A promising alternative is rapid slag analysis using Laser OES. This technology requires no complex sample preparation and provides fast, precise measurements. In the round-robin tests, the accuracy of Laser OES was comparable to fused-bead XRF results, while delivering data much faster. This allows operators to obtain near real-time feedback and make precise, timely adjustments to slag practice.

This presentation will show the performance limits of today's common slag analysis approach, present modern alternatives, and discuss the possible impacts on EAF process control. With better analytical tools, the idea that "make the slag, and the steel makes itself"becomes increasingly achievable.

Speaker Country:

Germany

Speaker Company/University:

QuantoLux Innovation GmbH

Slag control and refractories II / 99

Modern in-situ Slag adjustment for EAF, BOF, LF, and VD Steelmaking

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Slag is a critical factor in all major steelmaking routes, including EAF, BOF, LF, and VD processes. It affects refining efficiency, energy consumption, refractory life, and overall process stability. Traditionally, slag chemistry is measured using pressed pellets and X-ray fluorescence (XRF). While widely used, this method has some limitations: sample preparation takes time, heterogeneous or granular slag is difficult to analyse accurately, and light elements such as Si, Mg, and Al are challenging to measure reliably. These issues can slow down decision-making in the melt shop and create uncertainties in process control.

A modern alternative is in-situ slag analysis using Laser Optical Emission Spectroscopy (Laser OES or LIBS). This method provides rapid, precise, and preparation-free measurements of slag composition, including major and light oxides. By giving near real-time chemical data, LIBS allows operators to monitor slag continuously and make fast, informed process adjustments.

This presentation shows case studies from steel plants using EAF, BOF, LF, and VD steelmaking. The examples demonstrate how rapid slag analysis enables proactive interventions, improves refining performance, optimizes energy use, and reduces refractory wear. Customers also report better control of alloying additions and faster responses to process changes.

The results show that modern, rapid slag analytics improve measurement precision and support operational decision-making, leading to economic and process benefits. These case studies highlight that advanced in-situ slag analysis is not just a technological improvement—it is a practical tool for faster, more precise, and cost-effective steelmaking.

Speaker Country:

Germany

Speaker Company/University:

QuantoLux Innovation GmbH

Energy Efficiency and Consumption Reduction / 100

Driving efficiency in stainless steel production: Demonstrated impact of electromagnetic stirring on a 65-ton AC electric arc furnace at Walsin Lihwa

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The steel industry is under continued pressure to enhance efficiency to satisfy financial and sustainability goals. In stainless steel production, higher alloying costs and more complex process control requirements create additional challenges. At Walsin Lihwa's Yenshui plant, two persistent issues - non-uniform bath temperature distribution and bottom skull formation - were limiting melting efficiency and increasing energy consumption for their 65-ton electric arc furnace (EAF). To address these challenges, electromagnetic stirring (EMS, ArcSave®) technology was implemented in 2025 and evaluated through hot commissioning and performance testing. EMS improved thermal homogeneity and melt flow, reducing electric energy consumption by 2.5–3.5% for standard stainless steels, with additional savings for high-alloy grades. Electrode consumption decreased by 5.6% and gunning refractory usage on the slag-line area was reduced by 45%, owing to improved heat distribution and minimized cold spots. Oxygen demand was lowered by approximately 100 Nm^3 per heat, while scrap yield increased by 1–2%. All contractual performance guarantees were met, confirming EMS as an effective metallurgical solution for process optimization and sustainability. The paper also presents EMS system tailor-made design, installation challenges, and control strategies, supported by electromagnetic field simulations using Dassault Opera® and CFD modeling in ANSYS Fluent®. The stirring velocity and energy within the melt are illustrated in Figure 1. These simulations guided the optimization of stirring profiles, demonstrating EMS's capability to accelerate scrap and ferroalloy melting, enhance metallic yield, and improve productivity in stainless steel smelting. The EMS system features an automated whole bath stirring profile, intelligently adjusting stirring direction and velocity to match the requirements of each EAF process step, very low maintenance and reliable operations.

Speaker Country:

Sweden

Speaker Company/University:

Walsin Lihwa Corporation

Scrap management and quality improvement / 101

Engineering Rapid Automotive Materials Sustainability (e-RAMS): Upstream conditioning of ELV scrap for high-quality steelmaking

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Steel decarbonisation is accelerating an infrastructural shift from Basic Oxygen Furnaces to scrap-based Electric Arc Furnace steelmaking. This shift places far greater reliance on post-consumer scrap streams, particularly end-of-life vehicles (ELVs), which supply 1.5-2 Mt of scrap annually in the UK and 8-9 Mt across Europe. Blending high-grade automotive steels with mixed co-materials can result in residual concentrations beyond specification thresholds, forcing downgrading into lower-value products and eroding material efficiency and decarbonisation potential.
While copper remains the dominant tramp element in ELV scrap, less attention has been given to nickel and tin despite their distinct accumulation behaviour in high-scrap EAF systems. Neither

element is removed by standard pre-processing, so even modest concentrations persist through multiple recycling cycles. Small additions of tin can trigger hot shortness and intergranular cracking, while unintended nickel pick-up alters hardenability and transformation behaviour in low-carbon strip grades.
The e-RAMS project evaluates whether upstream removal of Ni- and Sn-bearing components can viably improve ELV scrap quality before shredding. Laboratory sampling and XRF screening across multiple makes and models identified a consistent set of contributors: exhaust sections, door-striker plates, turbocharger housings and related parts typically contained 7-13% Ni, while electrical fuse prongs and soldered connectors contained 40-42% Sn. These findings guided intervention trials at two Authorised Treatment Facilities (ATFs), where targeted component removal was applied to 20 vehicles per site to capture variation in business models, layouts, tooling and workforce practices.
A business-as-usual batch of 20 ELVs was also processed. All 60 vehicles were subsequently shredded at an industrial partner, producing three scrap streams that underwent assay melting and composition analysis. Based on these data, system-level modelling was carried out to examine cumulative Ni and Sn aggregation in ferrous scrap under a bounded UK scenario in which similar dismantling interventions are widely adopted. The modelling indicates that targeted removal of a limited family of Ni/Sn-bearing components could materially slow the long-term build-up of these residuals in EAF-based steels and extend the viable window for high-recycled-content automotive grades before specification limits are reached.
Overall, the results show that one to two hours of additional dismantling time per ELV, focused on a small family of high-impact components, can deliver meaningful improvements in melt chemistry with limited operational disruption. By linking dismantling practices with furnace-level metallurgy and long-term residual management, the study aligns with EEC 2026 and EMECR 2026 priorities on scrap quality, alloy control, circularity and resource-efficient steelmaking.

Speaker Country:

United Kingdom

Speaker Company/University:

Coventry University

Automation and Digitalization in Electric Steelmaking II / 102

Sensor and digital twin solutions developed in DiGreeS project for improvement of scrap-based EAF steelmaking

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On the path toward low-carbon steelmaking and increased circularity, the Electric Arc Furnace (EAF) will be pivotal for European steelmakers. Within the EU-funded Horizon Europe project "Demonstration of Digital twins for a Green Steel value chain (DiGreeS)"an integrated digitalisation approach is being developed across the steel value chain to leverage process data and human experience for seamless industrial integration. DiGreeS aims to deliver a user-friendly digital platform

for networked production, built on novel and soft sensors and related process models to support efficient feedstock verification and real-time control in EAF steelmaking. Artificial intelligence (AI) techniques will be fully exploited to optimise industrial data usage.
The presentation highlights concepts and first results from two DiGreeS use cases focused on scrap-based EAF steelmaking.
The first use case targets Heavy Melting Scrap (HMS) verification using camera images and surface chemical analysis (LIBS) to provide bulk analysis of HMS truckloads with emphasis on copper and sulphur content. Sensor data will be used to train an AI model to classify the HMS pieces and assign a "representativeness indicator"to pieces of each class. This approach aims to minimise unexpected impurity levels in scrap input and improve the crude steel quality. The presentation will cover sensor selection, adaption, calibration, software development and first laboratory trial results.
The second use case addresses real-time EAF control focussing on assessment of foamy slag quality, and built on that, control and optimisation of carbon and oxygen input for increased energy efficiency. Sensors such as acoustic emission and structure-borne vibration sensors as well as an in-situ off-gas measurement system will be installed at the Saarstahl Ascoval furnace. Their data, together with the arc current harmonics analysis and slag balance calculations, will feed an AI model for comprehensive foamy slag quality assessment, which will be embedded in an existing dynamic EAF process model for enhanced on-line process monitoring and control. The presentation will report on the sensor and process model configuration and first results of their implementation at Ascoval' s EAF.

Speaker Country:

Germany

Speaker Company/University:

VDEh-Betriebsforschungsinsitiut

Innovations in EAF Technology I / 103

Energy-Optimized, Emissions-Reducing Technologies for EAF Steelmaking

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Linde's CoJet® gas-injection technology, introduced in 1996 and now installed in over 175 EAFs, has become the industry standard for chemical energy input. To further decarbonize EAF operations and improve process efficiency, Linde has developed three hydrogen-ready systems: the 3-in-1 Injector, the Fluidic Burner, and the OPTIVIEW® flue-gas monitoring system.

OPTIVIEW® provides continuous, image-based flue-gas analysis, enabling real-time post-combustion control and reduced energy losses. The 3-in-1 Injector integrates oxygen lancing, carbon injection, and burner mode in a single sidewall unit. Its supersonic oxygen jet fluidizes and accelerates carbon for highly efficient delivery to the bath and slag–steel interface, improving slag foaming, refining, and carbon-use efficiency. It also enables injection of DRI fines or lime, supporting the industry shift toward DRI-based, low-carbon ironmaking. The Fluidic Burner uses fluidic oscillation to dynamically move the flame and melt more scrap, especially near the slag door or EBT.

As part of the GreenHeatEAF Consortium, Linde played a key role in on-site trials at SWERIM. The trials demonstrated that Linde CoJet burners can achieve good results with hydrogen as fuel compared to natural gas, even with different feedstocks such as DRI, scrap, or similar materials.

This paper summarizes these technologies and their demonstrated performance in enabling lower-carbon, hydrogen-ready EAF steelmaking.

Speaker Country:

Canada

Speaker Company/University:

Linde

Safety and Training I / 104

Improving Safety in Steelmaking Operations through Advanced Computer Vision and Machine Learning within the iSteel-Expert Project

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The iSteel-Expert project pioneers an advanced computer vision and machine learning framework for monitoring and analysis of Electric Arc Furnace (EAF) operations within steel plants. Co funded with the European Research Fund for Coal and Steel (RFCS) G.A. 101112102, the project's core mission is to develop a remote expert virtual system that enhances operator situational awareness, preserves expert knowledge, and fosters improved safety and process efficiency in 24/7 industrial environments.

This presentation focuses on the deployment and performance of several AI-powered vision modules designed to monitor critical aspects of the melting phase:

1. Human presence detection
   Leveraging deep-learning object detection architectures, the system identifies personnel presence in high-risk zones around the EAF. This ensures that operators are aware of human location relative to hazardous operations, reinforcing safety protocols and minimizing accident risk.

2. Electrode smoke detection
   A deep-learning model analyzes images to detect early signs of fumes emissions around the electrodes and roof. Building on pretrained convolutional neural networks via transfer learning, this module extracts visual cues to flag potential occurrences of dangerous reactions.

3. Slag door state detection
   By analyzing camera feeds near the slag door, the system classifies whether the door is obstructed. This capability supports automated tracking of slag-removal timing and alerts operators to abnormal or unsafe states.

4. Electrode movement speed estimation
   Applying optical flow and frame-to-frame correlation, the system determines the position of the electrode and its up-and-down velocity. Movement monitoring provides critical insights into process control and identifies potential mechanical or control system degradation.

5. Electrode-tip shape monitoring
   Leveraging convolutional neural network-based segmentation, the system models and periodically assesses the electrode's tip geometry. Detecting anomalies or wear extends electrode life, minimizes unplanned downtime, and informs maintenance planning.

These modules form part of iSteel-Expert vision system which integrates cutting-edge AI techniques to reinforce safety, optimize process efficiency, and enhances knowledge preservation in steelmaking operations.

Initial deployment within the industrial EAF environment in Pittini Siderpotenza demonstrate reliable detection performance and alerting capability, supporting improved process transparency and operator decision-making. Moreover, the results highlight the potential for broader application of computer vision in the metallurgical domain and underscore the value of multidisciplinary collaboration in Industry 4.0 transformations.

Future work will focus on large-scale validation of KPIs, refinement of AI modules, and training system assessments.

Speaker Country:

Italy

Speaker Company/University:

Tenova

Renewable gases and CO2 mitigation in steel industry I / 105

Circular Carbon and Electrified Heat: Carbon neutral Syngas heated by Paul Wurth Tempra to reduce Blast Furnace CO_2 Emissions

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Decarbonizing existing Blast Furnaces is a critical challenge for integrated steel plants aiming for climate neutrality. This paper introduces a technological pathway that uses thermal dry reforming of coke plant by-products and Paul Wurth Tempra for electric gas heating in a top gas recycling Blast Furnace scheme.
SMS group has developed the OXYTAR technology, which converts the hydrocarbons contained in the coke oven gas (COG) and coke oven plant by-products (tar, coke fines) into high-quality reducing gas through thermal dry reforming at temperatures up to 1400°C. Pilot campaigns at an industrial coke oven plant validated the technology at TRL6, achieving syngas compositions suitable for effective use in the Blast Furnace process. The direct injection in the Blast Furnace Shaft of this syngas once mixed with other available steelmaking gases, transforms waste streams into valuable feedstock, supporting circularity and lowering Scope 1 CO_2 emissions from Blast Furnaces in retrofit configurations.
To maximize efficiency and eliminate fossil fuel combustion in hot stoves, SMS group has developed the Paul Wurth Tempra system for electric heating of syngas to temperatures exceeding 1100°C. This electrification step, which can be powered by renewable electricity, ensures precise thermal control, high energy efficiency (>97%), and compatibility with hydrogen-rich blends when integrated with Top Gas Recycling Blast Furnace (TGR) with CO_2 removal.
These combined technologies enable an opex friendly staged decarbonization: starting with a 30% CO_2 emission reduction by utilizing internal available streams in integrated steel plants and reaching

up to 70% with the incorporation of hydrogen in the top gas recycling loop, according to ISO 14404 CO_2 emission calculation standards.
Tempra system, combined with existing hot stoves, offers a unique solution for leveraging the variable cost of renewable electricity throughout the day in a Thermal Energy Storage configuration. This minimizes the cost of electrical power, which is typically a concern in areas where existing blast furnaces operate.
The proposed solution provides a scalable and staged retrofit strategy for existing blast furnaces, minimizing CAPEX while aligning with emerging green steel standards. Beyond CO_2 emission reduction, the concept enhances energy efficiency, valorizes by-products, and offers a flexible platform for future integration with hydrogen and carbon capture/utilization (CCU).
This paper will detail the process fundamentals, energy balances, and implementation scenarios, demonstrating how OXYTAR and Tempra can accelerate the transition toward low-carbon ironmaking without compromising productivity and providing the best OPEX and CAPEX when natural gas is not available.

Speaker Country:

Italy

Speaker Company/University:

SMS group, Italy

Innovations in EAF Technology I / 106

FESCON SYSTEM: TRANSFORMING STEEL TO GREEN

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In the steel production process, the Scrap Preheating Technique, which heats scrap to approximately 700℃ through Electric Arc Furnace melting, enables a significant reduction in electrical energy consumption and, consequently, an increase in furnace efficiency. ”Furnace Energy Saving & Continuous Charging (FESCON) System”developed by GEMKOM, is a patented technology that brings significant transformation to steel production processes through its "environmentally friendly"and "high-efficiency production", making it superior to existing systems. Adopted by pioneering company like KARDEMIR HADDECILIK, this innovative system integrates advanced methods for scrap preheating, resulting in substantial improvements in emission reduction, productivity enhancement, and energy efficiency. The successes achieved by KARDEMIR HADDECILIK with the FESCON system highlight the importance of leading initiatives towards environmentally friendly steel production. Key design features of the FESCON system include efficient scrap preheating, reduced dust emissions, increased process stability, and optimized energy consumption. The achievements of Kar-Demir with the FESCON system also inspire other companies in the sector to take further steps towards environmentally friendly steel production, emphasizing the significant transformation brought about by innovative, sustainability-focused solutions in the industry. Among all the advantages, one feature is giving the operational flexibility that FESCON is the only system on the market where you can continue operation by taking FESCON system to parking position where all other pre-heating technologies on the market is not giving such flexibility since they are strictly combined with EAF.

Speaker Country:

Turkey

Speaker Company/University:

GEMKOM MAKINA

Automation and Digitalization in Electric Steelmaking II / 107

Scrap-Aware Adaptive Process Control for Electric Arc Furnaces

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This presentation introduces a scrap-aware adaptive electrode and process control concept for Electric Arc Furnaces (EAFs). The system performs an in-situ scrap classification based on process-integrated signals to identify scrap stratification, density distribution and expected melting behavior. These indicators drive an adaptive control layer that continuously adjusts transformer tap position, reactor step, and phase-specific current setpoints representing arc length. Control characteristics are automatically switched according to prevailing scrap conditions, improving arc stability across bore-down, melting, and refining phases. A simplified melting model estimates remaining scrap height and supports optimized burner coordination. Plant trials show improved arc stability, energy efficiency, and reduced melting time, particularly for heterogeneous scrap mixes.

Speaker Country:

Austria

Speaker Company/University:

INTECO melting and casting technologies

Future Directions and Emerging Technologies / 108

Energy and CO_2 Reduction in Steel Reheating and Hot Rolling through Intelligent Furnace Control and Delay-Aware Process Integration

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Steel hot rolling is a critical downstream process in steel production and remains highly energy-intensive due to reheating furnace losses, unplanned mill delays, and insufficient coordination between furnace operation and rolling schedules. While significant progress has been achieved in improving energy efficiency and decarbonization in primary steelmaking, downstream processes such as reheating and hot rolling still present substantial opportunities for reducing fuel consumption and associated CO_2 emissions.

This work presents an intelligent process integration framework aimed at improving energy and material efficiency in steel reheating furnaces supplying blooms to a hot bar rolling mill. The proposed approach integrates real-time thermal monitoring, delay-aware furnace control, and rolling process constraints to minimize unnecessary overheating and idle fuel consumption during mill interruptions. Unlike conventional furnace operation strategies that maintain fixed temperature setpoints regardless of rolling conditions, the developed control methodology dynamically adjusts fuel input and furnace operating parameters based on predicted rolling delays and discharge requirements.

A digital process model representing furnace heat transfer, bloom thermal evolution, and rolling time–temperature constraints is employed to quantify energy losses under conventional and intelligent operating strategies. The model enables real-time estimation of bloom surface and core temperatures, allowing the furnace to operate closer to optimal thermal limits without compromising rolling quality or productivity. Special emphasis is placed on managing energy losses during short- and medium-duration rolling delays, which are commonly encountered in industrial rolling mills and contribute significantly to excess fuel usage and CO_2 emissions.

The proposed framework was implemented and evaluated on an industrial pusher-type reheating furnace with a production capacity of 25 t/h supplying a hot bar rolling mill. Comparative analysis between conventional furnace operation and intelligent delay-aware control demonstrates a measurable reduction in specific fuel consumption and corresponding CO_2 emissions, while maintaining required rolling temperatures and dimensional quality of the rolled bars. The results confirm that intelligent integration of reheating and rolling operations can play a significant role in achieving energy efficiency and decarbonization targets in the steel industry.

The study highlights the importance of extending digitalization and intelligent control strategies beyond primary steelmaking to downstream processing stages. The proposed approach supports sustainable steel production by improving energy utilization, reducing emissions, and enhancing operational flexibility, in alignment with the objectives of EMECR 2026.

Speaker Country:

India

Speaker Company/University:

Guru Nanak Dev Engineering College, Ludhiana

Automation and Digitalization in Electric Steelmaking III / 109

CFD modeling of supersonic jet impingement on molten bath during electric arc furnace refining

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Electric arc furnaces (EAFs) have become a key steelmaking technology in recent years. Today, more than 70% of steel produced in the United States comes from EAFs, which can reduce carbon emissions by up to 55–60% compared with the traditional blast furnace–basic oxygen furnace route. This makes EAFs a critical pathway for decarbonizing the steel industry. Despite these advantages, further improvements in refining efficiency and process understanding are essential to meet increasingly stringent sustainability and productivity goals. During the refining stage of EAF operation, supersonic oxygen injection is employed to enhance molten steel stirring, control steel composition, and promote slag foaming, which shields the electric arc and improves thermal efficiency. The behavior of these supersonic jets governs cavity formation, momentum transfer, and bath circulation, all of which influence refining performance. However, these jet–bath interactions occur under extreme thermal and chemical conditions, making direct experimental measurements inside industrial furnaces extremely difficult. Computational fluid dynamics (CFD) has therefore become an indispensable tool for studying complex phenomena such as supersonic injection in actual EAFs. Modeling supersonic injection in EAFs poses significant challenges, including compressible turbulent flow, free-surface deformation, multiphase interactions among gas, molten steel, and slag, and highly transient behavior. These complexities demand advanced numerical methods, careful mesh design, and robust solution strategies to maintain stability and accuracy. In this study, an advanced CFD framework based on the volume-of-fluid (VOF) formulation is developed to examine coherent jets injecting oxygen at different Mach numbers during the refining stage. The simulations are based on the geometry and operating conditions of an actual industrial furnace. To balance computational cost with realistic representation, the model focuses on a section of the furnace rather than the full geometry. Jet angle and position, as well as stand-off distances are selected according to typical industrial practice to ensure relevance. Simulations are used to evaluate coherent jet performance at Mach 1 and Mach 2, providing insights into their effects on cavity dynamics and molten steel mixing. The findings contribute to a deeper understanding of supersonic injection behavior and support the development of industry-relevant guidelines for refining-stage optimization.

Speaker Country:

United States

Speaker Company/University:

Purdue University Northwest

Slag control and refractories I / 110

Process improvements by real-time on site analysis of metallurgical processes

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Currently, the European steel industry is undergoing a transformation, driven by two major forces. Firstly, to stay competitive in difficult market situations, new ways to improve processes, reduce losses and increase resource efficiency have to be developed. Secondly, economic and regulatory forces drive a transition of the steel industry towards production processes with lower carbon emissions.

One result is the transformation from the established BF+BOF process to electrical steelmaking with DRI/HBI and scrap as the primary iron sources.
With DRI come two major challenges. One the one hand using DRI changes slag compositions compared to the blast-furnace slag, changing steelmaking, but also valorization-possibilities of the slag. On the other hand, DRI is much different from pig-iron as it is not fully reduced and also carries high amounts of gangue material and different contents of carbon.

SECOPTA can show, that by using the LIBS-technology and fast, real time onsite analysis steel production via the DRI-EAF route can be controlled more efficiently. This tight process control enable producers to increase yield and reduce energy consumption and waste of resources.

Speaker Country:

Germany

Speaker Company/University:

SECOPTA analytics GmbH

Safety and Training I / 111

Reducing Power-Off Times Through Maintenance, Training, and Standardization

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Power-off time (POFF) is a key driver in electric arc furnace (EAF) steelmaking for productivity, energy efficiency, operation costs, and CO_2 performance.
Consequently, Badische focuses on the human and organizational dimension of POFF reduction. Top equipment can only bring financial benefits when it is operated and maintained well in the long run. Improving maintenance strategies, investing in workforce capabilities, and increasing the level of operational standardization became the main drivers. The objective is to move from reactive, failure-driven maintenance toward well-prepared, predictable execution during power-off phases. Examples at Badische's steel plant in Kehl, Germany and other consultancy customers of Badische are presented in this paper.
Clear task ownership, improved coordination between operation and maintenance, standardized procedures and consistent communication routines reduced variability and dependency on individual experience. Strengthening workforce capability and alignment enabled faster and more reliable maintenance execution without major capital investment.
The experience confirms that sustainable POFF reduction is largely determined by the human factor once technical limits are reached. Meaningful improvements in furnace availability, energy efficiency, cost reduction and CO_2 performance can be achieved by focusing on people, organization, and disciplined standardization rather than additional equipment upgrades.

Speaker Country:

Germany

Speaker Company/University:

Badische Stahl-Engineering GmbH

Recycling, circular economy and reduction of environmental impact in steelmaking II / 112

From Fossil Dependence to Energy Resilience: Biosyngas for Low-Carbon Steelmaking

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The steel industry faces increasing pressure to decarbonize while maintaining reliability, cost competitiveness, and product quality. While electrification and hydrogen play important long-term roles, many steel plants still depend on high-temperature thermal processes where fossil natural gas remains dominant. This creates an urgent need for scalable, renewable alternatives that can be deployed within existing infrastructure.

This presentation introduces biosyngas as a practical and industrially proven solution for reducing fossil fuel use in steel production. Produced on-site from renewable biomass residues, biosyngas can

directly replace natural gas in high-temperature applications such as reheating furnaces, annealing lines, ladle preheating, and other thermal processes critical to steelmaking.

Meva Energy's gasification technology enables continuous, stable biosyngas production tailored to industrial requirements. The talk will cover how biosyngas integrates with conventional steel plant operations, including burner compatibility, control systems, and safety considerations. Special focus will be placed on operational reliability, fuel flexibility, and how steel producers can decarbonize without compromising uptime or product quality.

Real-world project examples and performance data will illustrate achievable CO_2 reductions, typical substitution rates of fossil gas, and the role of locally available biomass in strengthening energy security. The presentation will also address key decision factors for steel producers, including CAPEX/OPEX trade-offs, regulatory drivers, and pathways toward net-zero strategies that combine immediate emissions reductions with long-term transformation.

By sharing concrete lessons learned from industrial deployments, this session aims to move the discussion from future concepts to actionable solutions—showing how biosyngas can serve as a bridge technology enabling the steel industry to decarbonize today, using proven technology and existing assets.

Speaker Country:

Sweden

Speaker Company/University:

Meva Energy

Recycling, circular economy and reduction of environmental impact in steelmaking I / 113

From Concept to Continuous Improvement –Stahlwerk Thüringen as a Lighthouse for RHI Magnesita's 4PRO Business Model

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Stahlwerk Thüringen (SWT) represents one of the most advanced real-world implementations of RHI Magnesita's 4PRO business model, demonstrating how the pillars **Performance**, **Partnership**, **People**, and **Planet** converge to drive continuous improvement and deliver measurable metallurgical, environmental, and economic value.

This success is rooted in a 30-year partnership, during which RHI Magnesita progressively established a commercial, fully digitalized Full Line Service (FLS) at SWT. Through professional refractory management, continuous monitoring, and structured maintenance concepts, specific refractory wear and total refractory costs in the EAF were reduced by approximately 50%. Further efficiency gains were achieved through closed casting practices, the introduction of tundish slide gate systems, and a shift toward monolithic lining concepts, significantly reducing refractory service-related OPEX.

Following these strong past achievements, the cooperation continues toward circular metallurgical additives and advanced slag engineering, provided by MIRECO, the joint venture of RHI Magnesita and HORN & Co.

The introduction of Circular Metallurgical Additives (CMA) and data-driven slag engineering, embedded in MIRECO's CERO Waste philosophy, established a holistic sustainability approach. This concept is transferable to regions where MIRECO operates, supported by local recycling and processing infrastructure. Through the incorporation of Refrattari Trezzi in the Milan region serves as one example of how such solutions can be enabled locally.

From a **Performance** perspective, replacing conventional EAF and ladle additives with CMA generated six-digit annual Total Cost of Ownership savings, complemented by additional six-digit savings through optimized slag practice and reduced manganese alloy consumption. Overall, SWT unlocked a value creation potential of approximately €1 million per year. Additional benefits include reduced refractory wear through the complete elimination of CaF_2 and shorter desulphurisation times enabling productivity gains.

The **Partnership** pillar is reflected in decades of trust-based collaboration and strong cross-functional integration. Direct on-site coordination by experienced technicians remains a key success factor.

From a **People** perspective, a Slag Engineering and Circular Additives Specialist supported implementation across all shifts, while teams from RHIM, MIRECO, and SWT—spanning Sales, Technical Marketing, R&D, Recycling, and Operations—ensured rapid adoption and stable execution.

From a **Planet** perspective, CMA substitution delivers CO_2 savings of approximately 11 kg per tonne of steel. Additional benefits include landfill avoidance, improved operator health, and groundwater protection.

This case demonstrates how 4PRO creates multi-level added value and is transferable to other regions. In particular, refractory recycling provides a proven pathway toward circular, high-performance steelmaking wherever MIRECO infrastructure is available.

Speaker Country:

Austria

Speaker Company/University:

RHI Magnesita

Poster session / 114

3D measurement assisted bottleneck reduction in stainless steel production

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Increasing steel weight per heat is a recurrent theme at many steelmakers to increase the productivity of the plant. This is generally limited by the volume of the various aggregates, EAF, Transfer ladle, AOD and casting ladle. The steel shells are fixed and cannot be modified easily. There is only the potential to reduce the size and shapes of the used refractory material. To avoid a negative impact on the lifetime and safety, a 3D measurement of the wear after usage can help to optimize the zoning of the refractory concept. RHIMAGNESITA has developed a new measurement system to support steelplants with this challenge. The new system is small and flexible, therefore it can be quickly moved and used in all areas. The paper describes several applications in different aggregates with focus on the volume enhancement of the AOD.

Speaker Country:

Austria

Speaker Company/University:

RHI MAGNESITA

Innovations in EAF Technology II / 115

BSE-EAF –Future-proof Melting. Automated System for safe, reliable & efficient operation

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Badische Stahl-Engineering GmbH (BSE) is one of the world leading engineering & consulting companies belonging to the RSE-Group (Reinforcing Steel Europe B.V.) with its own steel plant Badische Stahlwerke GmbH (BSW) both located in Kehl/Germany
Based on over 40 years of engineering, and even longer operational, experience & competence in the field of EAF-technology, BSE developed and provides its own unique EAF design and process technologies.
Key features and characteristics of the BSE-EAF are:
• Overall robust and reliable design of EAF-sections
• Well sized hydraulic system for safe and fast EAF motions
• Space saving gantry design
• Precise calculation and simulation of electrical power input system
• Reliable and efficient chemical energy system
• Customized shell dimensioning for given charge materials
• Modular equipment for quick change and safe maintenance
Beside all operational aspects of the design, also reliability and maintainability of the system sections are reflected in the design.
Currently BSE focused on developments to enable more and more automated and safe operation of EAFs. Key technologies in these field are:
• Safe-cooled roof by using spray-cooling
• Smart leakage detection for closed circuit cooling systems
• Safe-EBT with TapHoleManipulator and EBT-Sandman
• DoorMan for automatic sill cleaning and closed door operation
• Automated Sampling & Temperature measuring system with automatic cartridge changing by MultiRob
• Visual EAF-shell inspection by HD and HD-infrared cameras
The paper will show the technological backround of the mentioned features and characteristics. Furthermore realized installations will be shown for better explanation and a outlook of the current development activities will be given.

Speaker Country:

Germany

Speaker Company/University:

Badische Stahl-Engieering GmbH

Ladle metallurgy and slag control / 116

The Evolution of Tundish Working Lining Mass as the Example of Sustainability and Eco design of refractory masses

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The aim of this self-setting monolithic refractory mass was to be the example of the easy and clean tundish work lining performance for a steel plant. This contribution will present the history and the evolution of this tundish working refractory product in the Steelmaking world during this recent years. The development of Coldmag in Europe and America had its origin in 2007 and 2010 respectively, by a close cooperation with Celsa France and Arcelor Mittal (AM Olaberria in Spain and AM Acindar in Argentina), with a first paper and congress contribution in the IAS international Meeting in Argentina in 2011. The different requirements of the different steel producers forced and allowed Magna to introduce interesting modifications in the current tundish performance This paper shows the evolution and adaptation of the Coldmag self-setting tundish working lining enhancing the sustainability and the environmentally-friendly materials design.
This self-setting material basically consists in a dead burned magnesite in an adequate grain size distribution and special system of liquids binders added to shape the mass. The monolithic shape is achieved at room temperature, over a cold or a warm safety lining condition. The characterization includes X-ray diffraction and fluorescence analysis, thermogravimetric, mechanical resistance and thermal conductivity determination, considering the different developments introducing in the last years for fulfilling the worldwide customers requirements.
Including a continuous mixer machine, the application of this material is much easier and cleaner: no dust or vapors are produced. Health and safety conditions are improved using this system. The additives involved as well as the improvements regarding the row materials used, probably makes Coldmag self-setting material the most environmentally-friendly known way for tundish.
The energy and time efficiency, as well as the steel cleanliness, is noticeable enhanced using Coldmag. As a self-hardening material it does not need to be heated for its application.
Actually, Working together with our customers collaborators, this development allows us to close the circle of the sustainability by recovering and processing the refractory residues after the deskulling of the tundish.

Keywords: Self-setting; Environmentally-friendly, Tundish Working refractory lining; Circular Economy

Speaker Country:

Spain

Speaker Company/University:

Magnesitas Navarras, S.A

Process Control and Quality Improvement / 117

Implementation of Novel Tracing Techniques to Control Steel Cleanness in CO2-Neutral Steelmaking

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The European steel industry is urged to achieve CO_2-free production by 2050, as the iron and steel industry is a major contributor to global anthropogenic CO2 emissions and thus to global warming. The transformation of steelmaking will require established processes, such as the Electric Arc Furnace (EAF), and novel technologies, including Hydrogen Plasma Smelting Reduction (HPSR) and the Electric Smelting Furnace (ESF), to achieve crude steel production with near-zero direct CO2 emissions. Ongoing research mainly focuses on primary metallurgy, aiming to optimize the reduction process and increase the scrap rates. However, the quality of crude steel and the resulting requirements for subsequent secondary metallurgy have not yet been sufficiently quantified.
To ensure equal or even higher steel qualities under these evolving conditions, the application of tracing techniques is required to address causes by identifying the origin and understanding the formation of non-metallic inclusions (NMIs). Two innovative tracing approaches are the rare earth element (REE) fingerprint and the isotopic spiking with enriched stable isotopes. Both methods have different objectives in inclusion metallurgy. The use of the REE fingerprint technique enables the determination of the origin of NMIs without the addition of an external tracer by only measuring the natural concentration of REEs in auxiliaries and NMIs. Regarding the second approach, enriched stable isotopes are added to one component in the steel-slag-refractory system. By modifying the isotopic ratio of one potential source, it is possible to study occurring interactions without influencing the properties of the resulting NMIs.
These two tracing techniques enable the investigation of the impact of increased scrap rates and lower scrap quality on steel cleanness which is linked to higher tramp element content in steels. By now, the influence of the different tramp elements on steel properties such as steel cleannes is not fully known by today. Furthermore, these tracing approaches can also be applied to study the effects of modified input material mixes, alternative auxiliaries and alloying elements on secondary metallurgy. Accordingly, this study highlights the impact of tramp elements and underscores the importance and operational principles of these tracing methods for reliable cleanness assessment.

Speaker Country:

Austria

Speaker Company/University:

Technical University of Leoben

Innovations in EAF Technology II / 118

Digital Regulator-Based Control Strategies for Electric Arc Furnace

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At the ArcelorMittal Hamburg facility, steel production has long relied on electric arc furnaces (EAF), a process widely recognized for its resource efficiency and decarbonization potential. To further enhance operational performance, General Electric implemented a DirectFeed system, replacing the conventional static VAR compensator (SVC). This advanced high-voltage power conversion technology introduces a paradigm shift in furnace control by enabling continuous and decoupled regulation of voltage and current, thereby allowing dynamic adaptation to varying operating conditions and precise management of the thermal equilibrium within the EAF.

Beyond its documented benefits for grid stability, the system's novel control mechanisms deliver operational advantages. Ultra-fast response times facilitate dedicated arc length and power control, which can be leveraged to optimize energy efficiency, minimize refractory wear, and reduce the formation of leakages. Furthermore, the ability to tailor electrical parameters to distinct melting phases mitigates arc instability and improves process responsiveness, establishing a robust foundation for advanced, data-driven furnace operation.

Speaker Country:

Germany

Speaker Company/University:

ArcelorMittal Hamburg GmbH

Scrap management and quality improvement / 119

Conclusions of CAESAR HEU project - CirculArity Enhancements by low quality Scrap Analysis and Refinement

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Scrap plays a crucial role in steelmaking in order to enhance processes sustainability, as it reduces the reliance on virgin raw materials and supports the circular economy, while lowering CO_2 emissions and energy demand. However, current trends in the EU scrap market show a slight decline in pre-consumer scrap streams (E2, E6, E8, turnings, etc.) and a short- and long-term increase in post-consumer scrap availability (E1, E3, HMS…), driven by the growth in steel consumption over the past decades. Nowaday, these so-called "low-quality"scrap streams do not meet the requirements of several applications, which limits their use in steel production, particularly for flat products.
To expand steel scrap recycling capacity and improve energy efficiency, while maintaining EU competitiveness and securing supplies in terms of raw materials, energy, and climate impact, innovative technologies must be deployed to clean, upgrade, and valorize scrap before it enters steelmaking furnaces. Over a four-year period, the CAESAR project brought together steel producers, technology

providers, and research institutions to validate, at full industrial scale, integrated technologies for scrap upgrading, sorting, and characterization. The project's objective is to enable the local use of low-quality scrap streams in Europe while ensuring high product quality and creating valorization pathways for all recovered non-ferrous fractions, moving toward a zero-waste steel industry.
Close to the end of the project, several interesting results have been obtained on key topics:
• Mapping of the EU scrap market and characterization of exported low-quality grades –in particular with respect to locally consumed ones
• Selecting, testing and integrating the best available technologies to upgrade, sort and characterize lower-quality scrap
• Exploring advanced scrap cleaning and on-line characterization technologies
• Valorization of non-ferrous by-products generated by the upscaling steps and Life Cycle Assessment of the scrap upgrading compared to classical process
• Industrial scale validation of the technologies

The research leading to these results has been performed within the CAESAR project and received funding from the European Community's Horizon 2020 Programme under grant agreement n° 101058520.

Speaker Country:

Belgium

Speaker Company/University:

Centre for Research in Metallurgy (CRM)

Process Control and Quality Improvement / 120

Influence of copper and tin on the oxidic cleanness and investigation of the agglomeration tendency of non-metallic inclusions in a medium-carbon steel

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The European Green Deal and its consequences represent a disruptive change in steelmaking as the iron and steel industry contributes up to 7 % of total European greenhouse gas emissions. The goal to reach CO2-neutrality until 2050 requires a variety of new technologies such as direct reduction using hydrogen. Since the availability of both facilities as well as green hydrogen will not be sufficient, more established processes such as remelting of steel scraps in Electric Arc Furnaces (EAFs) are required as well. Therefore, it is essential to increase the recycling rate of steel which means that also lower quality secondary resources must be used which contain higher tramp element contents. These elements impact steels in various ways by, for example, affecting phase transformations or leading to hot shortness.
The research on tramp elements in steel until now has mainly focused on hot shortness or scaling during continuous casting and hot working while knowledge on interactions between tramp elements and non-metallic inclusions (NMIs) is still limited. The presence of copper and tin lowers the surface tension of steel melts. The authors have shown that this leads to an increase in nucleation of NMIs and changes wetting behavior, in turn affecting separation of NMIs into the slag as well as clogging. The first part of this study considers the effect of tramp elements on the agglomeration behavior of NMIs which is also influenced by surface tension and wetting behavior. Therefore, the movement of NMIs on the interface between steel and argon is tracked using High-Temperature Confocal Scanning Laser Microscopy (HT-CSLM). The attraction forces are calculated using the acceleration and

the calculated mass depending on the chemistry analyzed by Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM/EDS).
Furthermore, the behavior of NMIs on steel/slag interfaces is analyzed. for which a newly invented set-up for the observations of the interface through a liquid slag in the HT-CSLM is used. Therefore, larger synthetic spheres made of zirconia, silica, and alumina are added to the steel resembling different NMIs. These larger NMIs can be tracked even through the slag layer enabling the observation of agglomeration and repulsion as well as dissolution of NMIs when in contact with both steel and slag. The comparison of NMI movement in steels with and without tramp elements will provide valuable insights to retain or even improve the cleanness of steels made by remelting of low-quality scrap in EAFs.

Speaker Country:

Austria

Speaker Company/University:

Technical University of Leoben

Scrap management and quality improvement / 121

Image-Based Steel Scrap Mixture Recognition Using Deep Neural Networks

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Steel scrap recognition plays a crucial role in energy consumption optimization in the electric arc furnace (EAF) steel production process. Scrap picking for basket loading is traditionally in charge of the operator, who operates based on the expected charge mix. This process is prone to human operator errors. Scrap loads typically consist of heterogeneous mixtures of metal waste with diverse shapes and sizes, often comprising multiple scrap classes within a single batch. Thus, the scrap mixture recognition can be defined as estimating the contribution of scrap classes present in the load.
In this article, we propose a data-driven method for steel scrap recognition based on convolutional neural networks. We utilized ResNet50 architecture due to its excellent performance in image recognition tasks. To adapt the model to predict mixture proportions instead of one-hot class labels, the network is modified by replacing the original classification head with a trainable output layer and applying a softmax normalization. The model is trained using Kullback-Leibler (KL) loss function that directly compares predicted and annotated scrap class distributions. The dataset consists of approximately 46000 industrial images, annotated with soft labels representing mixture proportions and spans 21 scrap classes. The classes are a customer extension of standard European steel scrap specification EU-27. Training and evaluation are conducted taking into account the class imbalance. The model predictions, then, along with EAF operators' knowledge are processed with generative ai to suggest optimal furnace parameters and highlight potential issues between scrap mixture and furnace parameters.
Model performance is primarily evaluated using distribution-based metrics aligned with soft-label formulation of the problem. In particular, macro-averaged and weighted mean absolute error (MAE) are used to quantify deviations between predicted and ground-truth mixture proportions. The trained model achieves a macro-averaged MAE of 2.04% and a weighted MAE of 3.97%, indicating that predicted mixture compositions deviate from ground truth by only a few percentage points on average. Per-class error analysis shows that higher prediction errors are mainly associated with underrepresented classes.
These results demonstrate that convolutional neural networks are a viable solution for steel scrap mixture recognition in real industrial environments. Future work will focus on expanding the dataset beyond 100000 images, improving performance for low support classes, and exploring more expressive model architectures to further enhance accuracy.

Speaker Country:

Italy

Speaker Company/University:

Regesta s.p.a.

Automation and Digitalization in Electric Steelmaking II / 122

VISIOMAG: Advanced Technology for Safe and Efficient Refractory Monitoring in the Steel Industry

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The steel manufacturing industry faces increasingly demanding technological challenges, particularly regarding the safety, efficiency, and reliability of maintenance processes. One of the most critical issues is monitoring the condition of refractory linings in furnaces, ladles, and converters without exposing operators to risk or interrupting production. In response to this need, MAGNA—leveraging its extensive experience in robotic gunning for electric arc furnaces (EAF) and refractory repair—has developed VISIOMAG, a groundbreaking 3D scanning system that redefines how refractory health is assessed.
VISIOMAG is a wraparound system installed around the object to be measured, enabling a precise 3D reconstruction in just 15 seconds. Its compact, autonomous design eliminates the need for auxiliary machinery or risky proximity to high-temperature zones. Measurements can be completed in only 6 seconds, without halting steel production, representing a major advancement in operational safety and industrial efficiency.
A key advantage of VISIOMAG is its ability to function reliably under extreme conditions, such as smoke, intense heat, and radiation, without compromising measurement accuracy. The system delivers real-time, dependable data that supports strategic decision-making regarding refractory lifespan and helps prevent structural failures, perforations, and costly downtime.
Designed with usability in mind, VISIOMAG features an intuitive interface that allows any operator—regardless of experience—to interpret results and act quickly. It also includes an automated repair recommendation module, specifying the type of product and exact location for application, streamlining interventions and improving repair quality.
Currently, VISIOMAG is operational in two industrial plants. One of them has fully integrated the system into its production workflow, using its data to guide both maintenance planning and repair execution. This implementation has led to significant improvements in operational efficiency, personnel safety, and refractory durability.
With VISIOMAG, MAGNA delivers a cutting-edge solution tailored to the real needs of the steel sector, combining innovation, safety, and performance in a system that sets a new standard for refractory monitoring.

Speaker Country:

Spain

Speaker Company/University:

Terresis MAGNA

Successful implementation of electric steelmaking technologies & Best practices / 123

VIDEOMAG: high duty video technology applied to supervision of guning application in an EAF

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In the steelmaking industry, safety and precision during refractory maintenance are critical. MAGNA, with extensive experience in robotic gunning for Electric Arc Furnaces (EAF), has identified a key operational challenge: gunning is typically performed manually by an operator using a remote control, positioned near the furnace with direct visual contact. This exposes personnel to intense environmental stress and potential hazards such as heat, radiation, and refractory debris.
To address this, MAGNA has developed VIDEOMAG, an advanced video-based supervision system designed to enable fully remote gunning operations. The system integrates a high-resolution camera mounted on the gunning robot's head, transmitting real-time video to a monitor located in the EAF control room. This allows the operator to perform the entire gunning process from a safe distance, eliminating exposure to dangerous furnace conditions.
VIDEOMAG offers unmatched visual access to the furnace interior, with full 360° movement of the gunning head and superior image quality compared to direct observation from the furnace platform. The system is engineered to operate reliably in harsh environments, including high temperatures, smoke, and dust, ensuring consistent performance during refractory maintenance.
A key innovation of VIDEOMAG is its dual-camera capability: alongside the live video feed, it incorporates a thermal imaging camera that simultaneously captures temperature data. This enables operators to assess refractory conditions in real time and identify hot spots or areas requiring urgent attention. The system also supports inspection tasks, allowing detailed visual and thermal analysis of specific furnace zones at any time.
All operations are recorded, providing valuable footage for post-process review, quality assurance, and early detection of issues such as water leaks or refractory degradation. This enhances traceability and supports continuous improvement in maintenance strategies.
VIDEOMAG is currently in use at four industrial sites, where it has proven its value by significantly improving repair times, enhancing operator safety, and enabling early detection of leaks in cooling panels, helping prevent serious accidents. These results confirm VIDEOMAG as a transformative solution for EAF maintenance.
By removing the operator from hazardous zones and providing enhanced visual and thermal feedback, VIDEOMAG enables faster, safer, and more effective gunning applications—setting a new standard for remote refractory supervision in steel production.

Speaker Country:

Spain

Speaker Company/University:

Terresis MAGNA

New and emergent ironmaking Technologies I / 124

Co-combustion characteristics of PCI coal and alternative carbonaceous fuel for blast furnace operation

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This study experimentally analyzed the combustion characteristics of Biocarbon and Carbon Black as potential substitutes for PCI coal in the blast furnace process. Thermogravimetric analysis was employed to determine the basic combustion properties of each sample, while drop tube furnace and laminar flow reactor were used to evaluate combustion performance and visualize single-particle behavior. Based on these results, the limit injection rate for each fuel was derived. Four types of Biocarbon (BC300, BC400, BC500, BC800, classified by carbonization temperature), two types of Carbon Black (CB-I with high purity and CB-II with higher ash content), and one PCI coal as a reference. All Biocarbon samples exhibited higher reactivity than PCI coal, with reactivity decreasing as carbonization temperature increased. In contrast, both Carbon Black samples showed lower reactivity than PCI coal. DTF single-particle combustion tests indicated that BC500 and BC800 had the best combustion performance, while CB-I performed the worst. In co-firing experiments, BC400 and BC500 showed improved combustion from a 5% co-firing ratio, whereas CB-I exhibited reduced combustion performance with increasing co-firing ratio. LFR visualization revealed that BC300 produced a flame cloud typical of biomass combustion, while other Biocarbon samples exhibited fragmentation similar to coal, promoting combustion. CB-I and CB-II, with nano-sized particles, formed bulkier char particles due to strong electrostatic attraction. CB-II also showed extended combustion length due to its high ash content. In co-firing cases, all Biocarbon samples except BC300 exhibited increased combustion length, while Carbon Black samples showed reduced combustion length at 3% co-firing ratio, followed by an increase from 5%. To determine the limit injection rate for PCI application, three factors were considered: (1) combustibility, (2) heating value (HHV), and (3) ash content. The combustibility-based limit injection rate was found to be more restrictive than those based on HHV or ash content, indicating that combustibility is a critical factor in determining the feasible injection rate for alternative fuels in BF PCI operations. These findings provide essential insights into the operational feasibility of Biocarbon and Carbon Black as PCI coal substitutes, highlighting the importance of combustion performance evaluation in setting injection limits.

Speaker Country:

Korea South

Speaker Company/University:

POSCO Technical Research Laboratories

Recycling, circular economy and reduction of environmental impact in steelmaking I / 125

Research for Redesigning the Steel Scrap System

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The steel industry, which accounts for 7% of global anthropogenic CO2 emissions, is undergoing a major transition to reduce its carbon footprint, with several technologies being developed, trialled and commercialised at different scales, including scrap-based electric arc furnace (EAF), hydrogen direct reduced iron (HDRI)-EAF, hydrogen direct reduced iron (HDRI)-electric smelting furnace (ESF)-basic oxygen furnace (BOF), and iron ore electrolysis routes. All these new technologies have the potential to reduce CO2 emissions from 1.8~2.4 tonnes per tonne steel in the BF-BOF route to as low as 0.1 tonne CO2 per tonne steel if renewable energy is used. The scrap-based EAF route is particularly attractive because of its several advantages such as its proven capability at industry scale and the increasing scrap availability. World Steel Association estimates that the global end-of-life

steel availability will reach about 600 Mt in 2030 and 900 Mt in 2050. In the UK the annual scrap generation is over 11 Mt, exceeding its crude steel production of about 5.5 Mt per year.

The role of scrap in steel manufacturing has been evolving from serving primarily as a coolant in the BF-BOF route to becoming the main metallic raw materials in the (scrap-based) EAF route for producing certain high-quality steels that are traditionally made via the BF-BOF route. The scrap system, from generation and processing to quality assurance (including specifications) and efficient usage in steelmaking, must be redesigned to align with the evolving steel manufacturing landscape.

This talk will present a wide range of research activities undertaken by the authors to support the redesigning of the steel scrap system. Scrap standards and specifications are first examined in light of the evolving steelmaking technologies with recommended changes. Adopting circular economy principles during scrap generation and processing can substantially improve the scrap quality and value. One example to demonstrate is the automated disassembly of the end-of-life e-machines (compared to the current practice of shredding), enabling effective recovery of steels, aluminium and critical minerals and avoidance of contamination to scraps. Considering the urgent need of quality monitoring tools for the heterogeneous scrap, we developed a faster, smarter and more robust computer vision system, powered by a unique machine unlearning framework, for specific object identification and scrap quality assurance. The optimised scrap usage in steelmaking, in combination with OBMs (ore based metallics), is modelled considering steel chemistry, cost and environmental impacts.

Speaker Country:

United Kingdom

Speaker Company/University:

University of Warwick

Waste Management & Environmental Compliance / 126

Fundamental Understanding of Modified Electric Arc Furnace Slag for the Production of Electric Cement

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Electric Arc Furnace (EAF) steelmaking, because of its flexibility, high energy efficiency and low emissions, plays a critical role in decarbonising the steel industry. EAF slag is a CaO-SiO2-FeO-MgO-Al2O3 system, comprising 30~60% CaO, 15~25% SiO2, 2~10% Al2O3, 2~15% MgO, and 10~30% FeO, depending on different raw materials used and varying EAF operating conditions. Majority of EAF slag is used as an alternative to rock fragments in various construction applications. The use of EAF slag to produce supplementary cementitious materials (SCMs) has also been extensively studied by reducing its FeO content through various methods, however, it is still challenging.

To better utilise the EAF slag, a novel technology to directly produce Portland cement clinker in EAF steelmaking (i.e. electric cement) has been explored by adjusting the EAF steelmaking operating conditions. This new technology can produce low-carbon footprint cement clinker, supporting the decarbonisation of the cement industry, another hard-to-abate sector. This paper reports the fundamental understanding of modified EAF slags for producing electric cement through thermodynamic simulation, in-situ observation of high-temperature behaviours, and advanced characterisation of the modified EAF slags.

Understanding the formation conditions and mechanisms of tricalcium silicate (C3S - 3CaO·SiO2) phase in EAF slag is the key to enabling its utilisaiton for cement production because C3S is the principal hydration phase in Portland cement clinker. It was found that the C3S content in EAF slag exhibits a notable increase with increasing slag basicity and reaction time. The C3S formation mechanism in EAF slag is different from that in conventional Portland cement clinker production. It depends on the local conditions in the slag. In the lime-rich region it primarily takes place through the direct formation, i.e. 3CaO(s) + SiO2(l) = 3CaO·SiO2(s), controlled by the diffusion of SiO44− in liquid phase, while in the dicalcium silicate (C2S) rich region, C3S formation primarily occurs via the indirect formation: 2CaO·SiO2(s) + CaO(l) = 3CaO·SiO2(s), with the reaction being controlled by the diffusion of Ca2+ in the liquid slag. Cooling regime could play an important role in C3S formation. Rapid cooling from 1600 ℃ to room temperature at a cooling rate of -1500 K/min ℃ led to the formation of a large quantity of dicalcium silicate (C2S) and a calcium ferrite (CF) based slag with a small amount of C3S. Increasing the holding time at high temperatures facilitates the C3S crystal nucleation and growth, thereby increasing the C3S content in modified EAF slag.

Speaker Country:

United Kingdom

Speaker Company/University:

University of Warwick

Poster session / 127

Establishment and joint utilization of static and dynamic models for Baosteel electric arc furnaces

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Establishing mathematical models to predict the production status and process parameters of electric arc furnaces (EAFs) for guiding actual production holds significant importance. Based on the principles of mass and energy balance, this study developed a steelmaking model for ECS EAF. Through calculations with this model, parameters such as post-combustion energy utilization efficiency, oxygen utilization rate, and air inhalation ratio were obtained. These parameters were further incorporated into a dynamic model, which is established based on energy utilization efficiency and metallurgical reaction principles. A targeted comparative analysis was conducted to examine the effects of different processes on various steelmaking indicators of the EAF and to identify optimization directions. In the future, to optimize the steelmaking indicators of the EAF, it is necessary to further enhance the coordination of the oxygen-carbon injection, power supply, scrap feeding rate and strengthen post-combustion in the foamy slag.

Speaker Country:

China

Speaker Company/University:

Baosteel

Recycling, circular economy and reduction of environmental impact in steelmaking II / 128

Performance analysis and substitution potential of biomass charcoal as foaming agent for EAF

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Foamed slag technology is the core process of ultra-high-power electric furnace steelmaking, which is crucial for enhancing thermal efficiency, protecting furnace lining and optimizing molten steel quality. This paper takes biomass charcoal as the research object, systematically analyzes its performance and influencing factors as a blowing agent, and compares it with traditional fossil-based blowing agents (coke, graphite, anthracite). Waste wood block charcoal, corn stover charcoal, waste bamboo charcoal and industrial wood charcoal were used in the experiment, combined with chemically formulated electric furnace slag, and their foaming ability was evaluated by high-temperature foaming experiments with comprehensive foaming index (K). The results showed that the waste wood charcoal showed the best overall performance due to its high fixed carbon content and low ash content; the corn stover charcoal significantly reduced the viscosity of the slag due to its high ash content and high alkali metal content, resulting in the worst foaming area and duration; the waste bamboo charcoal, although with the highest fixed carbon content, had a high potassium content in the ash content that exacerbated the deterioration of the foam stability, and had a second best overall performance than that of the waste wood charcoal. Compared with fossil blowing agents, graphite showed the highest maximum foaming area and comprehensive index, but industrial wood charcoal showed substitution potential by virtue of its longer foaming time and low-carbon environmental protection characteristics. The study further revealed the synergistic effects of slag alkalinity, viscosity and surface tension on foaming performance, indicating that alkali metals (e.g., K, Na) in the ash fraction of biomass char reduced the viscosity by disrupting the silica-oxygen network, but an excessive amount shortened the foam life. This study provides a theoretical basis for the large-scale application of biomass char in electric furnace steelmaking, which is in line with the development needs of green metallurgy under the "dual-carbon"strategy.

Speaker Country:

China

Speaker Company/University:

Baoshan Iron and Steel Co., Ltd

AI and Machine Learning in Process Optimization II / 129

Temperature prediction model in an electric arc furnace based on data-driven

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Accurate prediction of molten steel temperature in electric arc furnaces plays a crucial role in optimizing steelmaking processes. However, the EAF smelting process is characterized by strong nonlinearity, complex multivariable coupling, and significant uncertainty, which pose substantial challenges to conventional mechanism-based temperature models.
To address these challenges, a data-driven temperature prediction model in an electric arc furnace is

proposed. A comprehensive dataset collected from an operating EAF is first preprocessed to remove noise and outliers. Key process variables affecting temperature evolution are identified through correlation analysis and feature selection techniques, including scrap amount, pig iron amount, lime amount, oxygen consumption, total power consumption, melting duration. These variables are used as inputs of temperature prediction models.
Several machine learning algorithms, including artificial neural networks, support vector regression, and ensemble learning methods, are developed and systematically compared to evaluate their prediction performance. The models are trained and validated using actual plant data, and their effectiveness is quantitatively assessed using standard statistical metrics such as mean absolute error, root mean square error, and the hit rate.
The results demonstrate that the data-driven models can effectively learn the complex mapping between process parameters and molten steel temperature, achieving higher prediction accuracy. The proposed approach offers a feasible and scalable solution for intelligent temperature management in electric arc furnace steelmaking and provides a valuable reference for the development of smart manufacturing in the steel industry.

Speaker Country:

China

Speaker Company/University:

University of science and technology Liaoning

New and emergent ironmaking Technologies II / 130

Hy4Smelt –Industrial Demonstration Project to Proof Potential Net-Zero Ironmaking by Combining Breakthrough HYFOR® and Smelter Technologies

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Achieving net zero ironmaking demands a fundamental shift away from conventional blast furnace routes, which remain among the largest industrial sources of CO_2 emissions due to their dependence on fossil fuels and limited integration of hydrogen. The Hy4Smelt industrial demonstration project addresses this challenge by combining hydrogen based fine ore reduction using the HYFOR® process with an electrically powered Smelter, enabling the production of potential net-zero hot metal avoiding carbon intensive up-stream processes.
Hy4Smelt builds on extensive development of both HYFOR® fluidized bed reduction and Smelter technology. The process eliminates the need for agglomeration and can treat (ultra)fine iron ores of all available qualities and mineralogies. This flexibility is increasingly critical as global ore grades decline and options for beneficiation and agglomeration become more constrained. The integrated Smelter efficiently processes lower grade direct reduced iron (DRI) with higher gangue levels, ensuring stable melting performance across a broad feedstock range.
An industrial demonstration plant is currently being implemented by a consortium comprising

Primetals Technologies, voestalpine, and Rio Tinto. Located at voestalpine's Linz site, the facility integrates HYFOR® fluidized bed technology producing up to 2.6 tons per hour of DRI with a Smelter designed for up to 2.4 t/h of green hot metal output. Fully powered by renewable electricity and supported by on site green hydrogen production via a PEM electrolyser, the plant aims to deliver hot metal and slag comparable in quality to blast furnace products while eliminating carbon intensive process steps. Continuous, near industrial scale operation will allow comprehensive validation of process performance, operability, and product quality.
This contribution presents the technological concept and current project status. Key topics include preheating strategies for (ultra)fine ores, reduction behavior within the HYFOR® reactors, and DRI fines handling, including HBI briquetting and alternative feeding methods into the Smelter. Focus areas at the Smelter include melting of fine and briquetted carbon-free DRI/HBI, management of varying metallization degrees, final iron oxide reduction in the slag phase, and hot metal carburization through secondary carbon sources. Additional attention is given to the utilization of the Smelter slag as a secondary cementitious material, highlighting the project's emphasis on circularity and resource efficiency.
The Hy4Smelt project is positioned to significantly reduce CO_2 emissions while establishing a new technological benchmark for sustainable ironmaking. Beyond its environmental impact, the demonstration plant will serve as an advanced digital showcase, a replicable blueprint for future climate neutral steel production facilities worldwide.

Speaker Country:

Austria

Speaker Company/University:

Primetals Technologies (tbd)

Poster session / 131

Valorization of Acid Regeneration Iron Oxide Residues into α-Fe_2O_3 Pigments by Chemical Routes

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In flat steel production, hot-rolled steel surfaces are subjected to acid pickling to remove surface oxide layers. During pickling, the iron concentration in the acid increases over time, and the spent acid is treated and recycled through an acid regeneration process. As a by-product of this process, iron oxide particles composed primarily of hematite and magnetite with an average particle size of approximately 1 mm are generated. However, these by-products are generally utilized in low-value applications despite their high iron content and pigment potential.
This work focuses on converting these iron oxide by-products into nano-sized red iron oxide (α-Fe2O3) pigment, contributing to waste valorization and circular material utilization. A two-step synthesis route was employed, in which ferrous chloride was first obtained via an acid leaching process, followed by controlled oxidation and calcination at temperatures between 500 and 800 ℃ to synthesize nano-sized α-Fe_2O_3.
The influence of calcination temperature on phase formation and particle size was investigated. Hematite formation was confirmed by XRD, while SEM–EDS and particle size analysis were employed to assess microstructural and compositional features. The results demonstrate the feasibility of producing nano-sized α-Fe_2O_3 pigment from steel industry waste through a scalable and environmentally sustainable process. This approach offers a sustainable pathway for the valorization of steel industry by-products, promoting circular material utilization and minimising industrial waste.

Speaker Country:

Turkey

Speaker Company/University:

Borçelik Çelik Sanayii Ticaret A.Ş.

Ongoing Research in Electric Steelmaking I / 132

All-Electric Plasma Torches as a Replacement for Industrial Gas Burners

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In the course of industrial decarbonization, the substitution of gas burners in industrial furnace systems is becoming increasingly important. All-electric plasma torches offer a viable alternative for retrofitting existing systems. These can be implemented without requiring a complete system overhaul.
Both electrode and electrodeless plasma systems are used. Electrodeless systems operate virtually wear-free and are therefore ideally suited for extended maintenance-free operation.
The system developed by XERION is based on plasma generation in an inductively coupled high-frequency electromagnetic field. This incorporates XERION's extensive experience in high-temperature furnace construction and its comprehensive expertise in inductive heating processes.
Results and experiences from a 65 kW experimental unit, built in-house and operated under variable conditions for several months, are reported. Part of the experimental unit is a gas-tight chamber directly flanged to the plasma torch. This allows for excellent analysis of the heat transfer from the torch to a furnace chamber. The behavior under various plasma gases and furnace atmospheres, such as argon, air, and hydrogen, is also tested. The use of hydrogen as the plasma gas is of particular interest because the reducing effect is significantly increased by ionization.
Key factors for the industrial application of these plasma torches are the achievable efficiency and the necessary long-term stability.
Furthermore, a 150 kW XERION plasma system is described, which will be operated on a rotary kiln as part of an international research project.
The outlook presents the possibilities for increasing the power output up to the megawatt range and the combination with various industrial furnaces. The use of novel silicon carbide-based power electronics components enables the cost-effective implementation of high-voltage, high-frequency circuits required to power the inductors.
The future application as direct firing of rotary kilns in the temperature range above 1,100℃ appears particularly promising.
These all-electric plasma torches can also be used as a replacement for auxiliary burners, such as those used in Electric Arc Furnaces. This allows such systems to be operated 100% electrically, eliminating the need for natural gas.

Speaker Country:

Germany

Speaker Company/University:

XERION BERLIN LABORATORIES GmbH

Automation and Digitalization in Electric Steelmaking I / 133

Optimized Scheduling for Electric Steelmaking: Integrating EAF, Secondary Metallurgy, Casting and Rolling for Throughput and Energy Efficiency

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In the electric steelmaking industry, short-term production planning often remains siloed, with process areas like the Electric Arc Furnace (EAF) melt shop, secondary metallurgy, and casting machine scheduled in isolation. This operational separation creates significant internal friction, manifesting as waiting times, inconsistent thermal profiles, and excessive energy consumption whenever inter-process synchronization falters.
We present a modern approach utilizing digital scheduling systems to unify these interdependent operations. We introduce a single, integrated process model built around a Mixed-Integer Linear Programming (MILP) core, which is further refined by a robust set of rule-based logic derived from expert operator knowledge and real-time plant data. This system generates a coordinated, executable production plan that ensures all steps from scrap charging to final casting are perfectly aligned.
An additional key capability is dynamic, reactive rescheduling. When unforeseen operational events occur, such as EAF delays, ladle transit variations, or caster disruptions, the system immediately performs a localized re-optimization. Unlike legacy systems that require a full plan rebuild, this approach adjusts only the necessary sequence sections, maintaining overall schedule stability and minimizing disruption to downstream processes.
Results from recent implementations across leading European and American flat-product electric mills illustrate substantial performance gains. These quantifiable improvements translate directly into maximized throughput, reduced operational costs, and higher on-time delivery reliability.
Ultimately, this integrated digital scheduling framework serves as a core pillar for operational excellence in modern electric steelmaking. By linking complex planning logic with plant KPIs and process automation, it empowers planners to evaluate performance scenarios in real-time, driving continuous improvement and accelerating the industry's digital transformation journey.

Speaker Country:

United States

Speaker Company/University:

Smart Steel Technologies

Integration of Renewable Energy & Biochar Applications / 134

Ecological assessment of the use of hydrochar in EAF operation based on an LCA approach

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Electric arc furnaces (EAFs) rely on carbonaceous materials (e.g., anthracite, coke breeze, or synthetic graphite) for slag foaming, oxygen refining, and energy efficiency. Replacing fossil-derived carbon with hydrochar, produced via hydrothermal carbonization (HTC) of biogenic residues, could lower the environmental footprint of steelmaking. Yet the net benefit depends strongly on feedstock

origin, process energy, and operational substitution rates. This study presents an ecological assessment of hydrochar use in EAF operation based on a life cycle assessment (LCA) framework.
The goal is to quantify potential environmental impacts and identify key drivers and trade-offs when hydrochar substitutes conventional fossil carbon in EAF practice. The LCA follows ISO 14040/14044 principles, applying a functional unit of "1 tonne of liquid steel produced in an EAF"and comparing a baseline fossil-carbon scenario with multiple hydrochar integration scenarios. Impact categories include climate change, particulate matter formation, acidification, eutrophication, resource use, and water-related indicators.
Results indicate that hydrochar can meaningfully reduce fossil carbon demand and associated greenhouse gas emissions, particularly when produced from residue streams with low upstream burdens and when HTC/drying energy is supplied by low-carbon sources or recovered heat. However, benefits may be offset by higher processing energy, increased ash handling, and potential trade-offs in acidification/eutrophication depending on feedstock cultivation and nutrient emissions. Hotspots typically include energy for dewatering/drying and the electricity mix, making decarbonized energy supply and process integration critical. The study provides guidance on environmentally robust hydrochar supply chains and operational conditions under which hydrochar contributes to lower-impact EAF steelmaking.

Speaker Country:

Germany

Speaker Company/University:

IOB - RWTH Aachen University

Successful implementation of electric steelmaking technologies & Best practices / 135

Secured EAF performance through process discipline —including constraints of raw material and experience

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Electric Arc Furnace (EAF) steelmaking plays a central role in the transition toward low-carbon and resource-efficient steel production. Increasing energy costs, environmental regulations and needed raw material flexibility demand continuous improvements in energy efficiency and process performance. The operating personnel in steelmaking plants getting younger, more than 10 years in the same profession has become rare. Building and maintaining deep-experienced staff as well as a highest level of safety is difficult.
This paper outlines key strategies for reducing electrical energy and material consumption in EAF operations through advanced process control, supportive smart-tools, and real-time data utilization. The integration of smart add-ones around the EAF combined with dynamic furnace control systems, including electrode regulation, foaming-slag control, and optimized oxygen and carbon injection, enables more stable process conditions, increased safety and lower downtimes. Raw material flexibility in EAF steelmaking is becoming increasingly important as the availability of high-quality scrap declines and competition for scrap intensifies which makes the entire situation even more difficult. The need to work with ore-based iron units is driven by quality requirements and the demand for cleaner steel. As a result, advanced process control and adaptive operating strategies are essential to maintain productivity, energy efficiency, and final steel quality under more variable raw material conditions.
Well-proven and reliable solutions for EAF process optimization from scrap yard until tapping are presented in this paper.

Speaker Country:

Germany

Speaker Company/University:

tripleS GmbH Co. KG

Slag control and refractories I / 136

EAF monitoring Solution By HERAEUS Electro-Nite

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Dear Scientific committee,

As the global market leader in monitoring and measurement solutions for steelmaking processes, Heraeus Electro-Nite is dedicated to advancing the industry through innovation. Our commitment to research and development enables us to deliver disruptive technologies that enhance efficiency, quality, and sustainability in steel production.

In recent years, we have proactively developed and implemented two emerging systems and integrated field equipment solutions for the Electric Arc Furnace (EAF) environment at several leading steelmakers worldwide: Chameleon/CoreTemp and Falcon. We would like to take this opportunity to introduce these solutions, designed to significantly improve existing process control systems.

By adopting these technologies, EAF steelmakers can significantly enhance operational safety through proactive automation, including fully automated, manless liquid metal temperature and oxidation (aO) measurements. Combined, these systems deliver a more comprehensive and valuable analysis of key parameters such as effective energy efficiency, energy transfer potential, bath homogeneity, and oxidation levels.

Recent installations have demonstrated strong interest from users, as these solutions deliver real-time bath status information. This capability has been directly linked to optimized tap-to-tap times, reduced energy consumption, improved power-on efficiency, greater process stability, and a potential reduction in CO_2 emissions—all while delivering a measurable improvement in operator safety.

Chameleon/CoreTemp are both designed to remotely measure liquid steel temperature during melting and refining phases. Its main feature is the ability to monitor temperature evolution by immersing a high-speed, specialized optical fiber into the melt through a horizontal or vertical cooling panel.

Falcon is developed to remotely monitor free Oxygen (aO) in liquid steel. The system launches a dedicated sensor at high speed through the EAF side panel (carbon injector or specific injector). This measurement is done remotely and can be taken during arcing at every liquid phase of operation. It helps to monitor in the early phase of melting the effective oxidation level.
This ensures fully safe operation (no personnel at steel), improved timing efficiency (no special measuring conditions required), and valuable data on aO behavior (early FeO monitoring and oxidation levels).

Together, either Chameleon or CoreTemp with Falcon, these systems provide strong and valuable comparative information on potential energy variations, energy transfer, and homogeneity issues related to scrap, weight, and bath level fluctuations.

.

Sincerely yours

Philippe BALLAND

Speaker Country:

France

Speaker Company/University:

HERAEUS ELECTRO-NITE

Future Directions and Emerging Technologies / 137

A System and Best Practice to Reduce Electrode Pin Breaks

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During EAF steel making, an electrode joint break is a highly disruptive event with significant implications to productivity and safety. It is well known, the quality of the electrode build practice is paramount to the integrity of the joint and will greatly reduce the probability of a pin break.
A poorly assembled joint has a very high risk of triggering a pin break, because it places practically all the mechanical stress on the pin. While it may seem simple to assemble a joint with a threaded pin and socket, there are a number of variables to control and several areas where it can go wrong. What is needed for the steel maker is a reliable method of achieving high quality electrode builds very consistently day-to-day. In this paper, we describe a system for quantifying the quality of electrode builds as well as best practices for the steel maker for achieving consistent electrode builds. We will show the difference between a good and a poor build, with several real-life examples. We will also illustrate how the implementation of a system and best practices reduces pin breaks and improves the consistency of operations.
When properly assembled, an electrode joint will have the necessary integrity to withstand EAF conditions and provide the best chance for optimal productivity and safety.

Speaker Country:

Switzerland

Speaker Company/University:

Graftech

Automation and Digitalization in Electric Steelmaking I / 138

Computer Vision-Based Copper Detection for Electric Arc Furnace Scrap Quality Enhancement

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The ongoing digital revolution across industrial sectors has positioned Deep Learning and Computer Vision as pivotal technologies for transforming conventional operations, particularly in waste management and material recycling. This transformation holds significant implications for Electric Arc Furnace steel production, where scrap metal serves as the principal feedstock. The efficiency and environmental performance of Electric Arc Furnace operations heavily depend on the characteristics of incoming scrap materials. Accurate categorization and assessment of various scrap grades are essential for enhancing furnace operations, reducing ecological footprint, and advancing Circular Economy objectives.
A critical bottleneck exists in enhancing lower-quality scrap streams through the detection and removal of contaminants, particularly copper, a process that currently depends on subjective manual evaluation and operator expertise.
This research describes the creation and assessment of an automated Deep Learning system for copper identification in ferrous scrap materials. The investigation forms part of the project entitled "Purity Improvement of Scrap Metal" (PURESCRAP, Grant Agreement 101092168), which is funded by the European Union through the Horizon Europe programme and is focused on maximizing the utilization of inferior scrap categories through implementation of advanced technological solutions for contaminant reduction.
A custom image dataset was assembled from photographs captured during on-site testing phases at scrap processing facilities. All images underwent meticulous manual annotation to mark copper presence and spatial coordinates, establishing the reference data required for training and validating the detection models. The research involved implementing and comparing two cutting-edge object detection frameworks to determine their effectiveness in this application.
The deployment of such automated detection systems addresses multiple operational challenges simultaneously. By replacing human visual inspection with machine learning algorithms, the approach offers consistent, rapid, and scalable contaminant identification. This technological advancement supports the steel industry's transition toward more sustainable practices by enabling better utilization of secondary raw materials that would otherwise be considered unsuitable for high-quality steel production. The outcomes contribute to both economic efficiency and environmental responsibility in steel manufacturing, demonstrating how artificial intelligence can facilitate industrial sustainability goals while maintaining production standards and reducing dependency on virgin materials.

Speaker Country:

Italy

Speaker Company/University:

Scuola Superiore Sant'Anna, Pisa

Successful implementation of electric steelmaking technologies & Best practices / 139

Operating experiences with Spray Cooled EAF conversion at SDI Columbia C

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In 2016, SDI's Structural and Rail Division (SRD) in Columbia City, Indiana initiated a strategic upgrade to its electric arc furnace (EAF) operation. The facility transitioned from pressurized tubular

water-cooled panels to a modern spray-cooled upper shell system. This enhancement aimed to address safety concerns, improve thermal performance, and lower maintenance demands. Over time, complementary technologies such as a spray-cooled roof, elbow, copper burner box, and the SYSTEMS Spray Safe Humidity Sensor were also introduced. This paper details the technical, economic, and operational benefits realized from these innovations.

Speaker Country:

United States

Speaker Company/University:

Systems Spray-Cooled

Industrial Symbiosis for the steel sector: opportunities, challenges and success stories / 140

Pilot-Scale Evaluation of Hydrochar Utilization in Electric Arc Furnace Steelmaking: Results from the BioReSteel Project

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The BioReSteel project, funded by the European Union's Research Fund for Coal and Steel (EU RFCS), has successfully carried out a pilot-scale electric arc furnace (EAF) campaign at Swerim in December 2025, aiming to validate the use of biomass-derived carbon materials as partial substitutes for fossil carbon in electric steelmaking. The campaign evaluated a range of hydrochar-based materials, including pristine and pyrolyzed hydrochar in pellet form, fine fractions, and hydrochar-iron oxide agglomerates, produced from low-grade wet biomass residues.

The pilot trials were designed to assess hydrochar performance under realistic EAF operating conditions and across key process stages, including melting, feeding, and refining. The materials were tested for multiple metallurgical functions relevant to EAF operation, such as carburization of the steel melt, reduction reactions, and slag foaming behavior, and were benchmarked against conventional fossil carbon materials. The experimental program generated a comprehensive dataset on process stability, material behavior, and operational compatibility.

Hydrochar production and upgrading were developed within an integrated value-chain approach, combining biomass valorization, quality optimization through controlled pyrolysis and phosphorus reduction, and adaptation to existing EAF charging and injection practices. Particular emphasis was placed on ensuring that the renewable carbon carriers could be applied without major modifications to current industrial equipment or operating procedures.

The results from the pilot campaign demonstrate the technical feasibility of hydrochar as a renewable carbon carrier in EAF steelmaking, showing stable process performance and promising functionality across the investigated applications. The outcomes provide a robust basis for the ongoing and forthcoming industrial-scale trials within the BioReSteel project and contribute to the development of low-carbon and circular solutions for electric steel production. This work supports the broader transition of the European steel industry toward reduced fossil carbon dependency, improved resource efficiency, and lower CO_2 emissions.

Speaker Country:

Sweden

Speaker Company/University:

Swerim AB

New and emergent ironmaking Technologies II / 141

Thermal and reaction analysis of iron ore agglomerates under hydrogen atmosphere

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Hydrogen ironmaking is considered a promising technology for achieving carbon neutrality in the steelmaking industry. Hydrogen reduction is an endothermic reaction, whereas the conventional CO reduction is exothermic. Therefore, the heat supply to the reaction site is an important issue. Macroscopically, heat is transferred by the hot reducing gas flow, and thermal-fluid analysis is a useful tool for designing the heat-supply process. On the other hand, the reduction reactions of iron oxide take place inside the particles of iron ore agglomerates because the agglomerates are usually porous. The accompanying heat transfer process also proceeds within a particle. Therefore, the simultaneous thermal and reactive behavior of the iron ore agglomerate is quite important as the fundamental information for the thermal design of the hydrogen ironmaking process. In this study, a mathematical model for the thermal and reaction analysis of hydrogen reduction of iron ore agglomerates was developed, and the thermal characteristics were discussed compared to the conventional CO reduction.
The mathematical model consists of the diffusion equation with a reaction term for the gaseous species within the iron ore agglomerate particle, the local reaction rate equations for the iron oxides, and the heat conduction equation. These equations were integrated using the gas concentration and gas temperature adjacent to the particle surface as boundary conditions. Then, the transient distributions of gas composition, solid composition and temperature can be obtained.
Under the CO reduction conditions, the iron oxide reduction proceeds by forming a reaction front, in other words, the reaction occurs within a thin region. Additionally, each reduction step holds its reaction front. Contrarily, the hydrogen reduction shows a broad reaction region, and multiple steps of the reduction reactions take place simultaneously at the same location. The particle temperature is affected by the reducing gas. Under the conditions allowing heat exchange between the particles and the surrounding gas, CO reduction exhibits a behavior in which the particle temperature initially rises due to the exothermic heat of reaction and then drops to the ambient temperature due to heat release to the surrounding gas. In contrast, H2 reduction exhibits the particle temperature drops and then recovers by receiving heat from the surroundings. A temperature difference also forms within a particle.

Speaker Country:

Japan

Speaker Company/University:

Tohoku University

New and emergent ironmaking Technologies II / 142

Biochar application for sustainable ironmaking using electric smelting furnace

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In order to help reduce the emissions from the global steel industry, many operators are looking to adopt the Electric Smelting Furnace (ESF), and utilising biocarbon as a substitute for fossil carbon to produce pig iron. The ESF can be operated using renewable electricity, and has the capability to treat low grade iron ore, making the ESF favoured in areas where low grade iron ore is abundant. In this study, an ESF process was modelled using Aspen Plus to understand the effect of biochar with varying chemical compositions on the smelting processes and product yield. When biochar with higher fixed carbon (86-92 wt%) was used in the ESF, hot metal production increased by 1.3-1.6 % compared to the biochar with lower fixed carbon (50 wt%), with molten iron in the hot metal ranging between 97.2-97.4%. Total hot metal of 847.5 kg and 849.6 kg were projected to be obtained from smelting 1000 kg of direct reduced iron with about 92 kg of the biochar with fixed carbon contents of 86% and 92%, respectively. More offgas (61.8 kg), mainly composed of CO, was generated from the lower fixed carbon scenario, compared to 34.5-41 kg of the offgas from the higher fixed carbon scenarios. Other components of biochar, such as oxygen and hydrogen, contributed to the higher offgas of the lower fixed carbon scenario. Although decomposition of the low carbon biochar required less energy, initiating the reactions in the furnace with dissolved carbon required higher energy. When the modelling results using biochar were compared to the furnace operation using fossil carbon, the fraction of molten iron in the hot metal remined unchanged, while offgas production decreased from 41 kg to 24.8 kg. The furnace was operated at 1600 ℃, which consumed about 728 kWh electricity for producing 1 tonne of hot metal (HM). Emissions from the use of 2024 Australian grid electricity with 45% coal, 17.2% natural gas, 1.7% oil, 36.1% renewables were estimated to be 417.9 kg CO2 eq/t HM, which could be reduced to 11.8 kg CO2 eq/t HM by using wind electricity.

Speaker Country:

Australia

Speaker Company/University:

Macquarie University

Integration of Renewable Energy & Biochar Applications / 143

Iron Ore Smelting System Using a Sustainable Coal-Based Direct Reduction and CO_2 Sequestration

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This study presents an innovative system developed within the AdriatiCO2 Project for the direct reduction of iron ore via a smelting process. The system substitutes conventional coking coal with sustainable carbon sources and/or biochar—a renewable reducing agent produced from biomass pyrolysis—and integrates efficient CO_2 capture to minimize the carbon footprint of steelmaking.

In the designed high-temperature reactor, the reducing agents act as both a reductant and an energy supplier. Its high reactivity and low impurities facilitate efficient iron oxide reduction while minimizing the slag formation. The resulting CO_2 emissions are captured using post-combustion sequestration techniques, such as amine scrubbing or mineral carbonation, to ensure near-zero emissions. Preliminary assessments indicate this approach could reduce CO_2 emissions by up to 80% compared to traditional blast furnace methods. Furthermore, the use of biochar derived from agricultural or forestry waste supports circular economy principles by valorizing biomass residues. The AdriatiCO2 Project will optimize reactor design, biochar properties, and CO_2 sequestration efficiency to enable industrial scalability. This system represents a viable transitional pathway toward greener steel production, aligning with global decarbonization goals while maintaining cost-effectiveness and material performance.

Speaker Country:

Italy

Speaker Company/University:

Politecnico di Milano

AI and Machine Learning in Process Optimization I / 144

A Hybrid Physical–Machine Learning Framework for Real-Time Bath Oxygen and Carbon Soft Sensing in DRI-Based Electric Arc Furnaces

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Reliable real-time knowledge of bath oxygen and carbon is a long-standing challenge in DRI-based Electric Arc Furnace (EAF) operation, directly impacting energy efficiency, decarburization control, and endpoint stability. This paper presents a novel hybrid physics-guided machine learning framework for continuous bath oxygen and carbon prediction, explicitly coupling metallurgical first principles with high-frequency operational data. The physical layer embeds oxygen and carbon mass balances, decarburization kinetics, carbon–oxygen equilibrium, and bath thermal evolution. A key innovation is the integration of time-series stack emission data—including CO, CO_2, O_2 concentrations and post-combustion rate—as dynamic indicators of in-furnace reaction intensity and oxygen utilization. Multiple machine-learning algorithms (Gaussian Process Regression, Artificial Neural Networks, and Long Short-Term Memory networks) were developed and benchmarked within the hybrid architecture. The selected model achieved R^2 values exceeding 0.9 for both oxygen and carbon across varying operating regimes, outperforming standalone physical and purely data-driven approaches. The proposed framework establishes a robust soft-sensing foundation for digital twin deployment, advanced EAF process control, and real-time energy optimization in industrial DRI-EAF steelmaking.

Speaker Country:

United Arab Emirates

Speaker Company/University:

EMSTEEL

Slag control and refractories II / 145

Implementation of Recycled Zr Slag band layer in submerged entry nozzle

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Refractory recycling has emerged as a key strategy in reducing the environmental impact of the steel and cement industries, where spent refractories often pose significant disposal challenges due to the presence of hazardous components such as bauxite, copper, magnesite, and chrome-bearing materials1,2. In line with its sustainability roadmap, RHI Magnesita is actively pursuing circular economy solutions to lower the carbon footprint of refractory products. Recycling not only conserves critical raw materials but also offers substantial CO_2 savings—up to 60% for mixed refractory linings and nearly 90% for unshaped products—compared to primary raw materials3.
This study presents a practical example of integrating recycled material into production: the partial substitution (50%) of standard raw material with High Zirconia Fused Cast (HZFC) material in the SEN slag band formulation. The modified product, containing approximately 10% recycled content, was trialed at the Bonnybridge plant. Material integrity and microtextural stability were preserved, with physical specifications comparable to those of the standard product produced using virgin raw materials. Subsequently, trials conducted using components produced with the recycled formulation confirmed consistent performance under industrial operating conditions, validating the feasibility of high-quality refractory recycling in practice.
This work underlines the strategic importance of recycling in refractories, not only from an environmental perspective but also for securing long-term raw material supply.

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Speaker Country:

Austria

Speaker Company/University:

RHI Magnesita GmbH

Recycling, circular economy and reduction of environmental impact in steelmaking II / 146

Biochar utilization in DRI-based EAF steelmaking

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Utilizing biochar in electric arc furnace (EAF) steelmaking has become a crucial step towards reducing fossil CO2 emissions. The present research examines the interaction between V2O5 and TiO2-containing EAF slag and pinebark-derived biochars, which were pyrolyzed at two different temperatures (600 ℃ and 800 ℃). Optical dilatometry (OD) and thermogravimetry (TG) studies, supported by X-ray diffraction (XRD) and scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS) characterization techniques, are utilized to elucidate the interaction. OD and TG were conducted by heating the carbonaceous material slag module at a rate of at least 10 K/min to 1500 ℃ in an inert atmosphere, followed by a 30-minute hold. This research focuses on understanding the following aspects of the interaction between the slag and the biochar: (1) the effect of pyrolysis temperature, (2) the effect of biochar structure, and (3) the impact of slag B2 basicity, FeO, V2O5, and TiO2 on the interaction. The preliminary results indicate that (1) the interaction between slag biochar and FeO is enhanced with an increase in slag FeO concentration and reduction in slag B2 basicity, and (2) vanadium is involved in solid solution formation with iron metallic droplets.

Speaker Country:

Sweden

Speaker Company/University:

Luleå University of Technology

Ongoing Research in Electric Steelmaking I / 147

Investigating the performance of Electric Smelting Furnace for green iron and steelmaking using feed material of varying quality: Insights from pilot-scale melting and hydrogen-based reduction trials

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The Electric Smelting Furnace (ESF) process represents a promising route for sustainable ironmaking by enabling the production of hot metal and slag suitable for steel and cement industries. A critical requirement for steel plant integration is achieving hot metal with a minimum carbon content of 3.0–3.5 wt% and controlled silicon levels (~0.4 wt%), while simultaneously producing marketable slag with low iron oxide content (<2 wt%). However, the mechanisms governing carburisation and melting in ESF remain insufficiently understood, particularly at relevant scales.
To address this, a series of pilot-scale melting trials were conducted at SINTEF, Norway between April 2022 and January 2024. The initial trial demonstrated the feasibility of melting 415 kg HBI with anthracite and fluxes, yielding hot metal with 2.4 wt% C and 0.1 wt% Si, but highlighted challenges in sampling and temperature control. Subsequent trials focused on increasing carbon input and improving operational practices. The second trial achieved 3.5 wt% C but resulted in elevated silicon (0.9 wt%) and slag contamination due to iron entrainment. The third trial introduced carbon-bearing DRI pellets, achieving consistently high carbon levels (~4.1 wt%) and acceptable silicon (~0.5 wt%), suggesting that internal carbon in DRI significantly enhances carburisation efficiency compared to external carbon sources. Nevertheless, slag iron oxide variability remained a concern, with values ranging from 1 to 21 wt%.

Complementary hydrogen-based reduction trials were performed to assess the suitability of TSN BF pellets with higher gangue content for ESF melting. In a rotary kiln metallisation degree of 85.0% was achieved under varying H_2 flow rates and durations, revealing limitations in reactor performance and declining H_2 utilisation at higher metallisation degrees. The partially reduced pellets from these trials were subsequently employed in a fourth melting trial in the SINTEF SAF furnace, which successfully demonstrated melting and carburisation under ESF conditions.
These investigations provide critical insights into the carburisation mechanism, the role of feedstock properties, and operational parameters influencing hot metal and slag quality in ESF. The findings underscore the importance of carbon distribution within the charge, slag-metal interactions, and reduction efficiency for scaling up ESF technology. Future work will focus on optimising slag chemistry and refining melting and carburisation strategies to meet industrial specifications.

Speaker Country:

Netherlands

Speaker Company/University:

Tata Steel Nederland

AI and Machine Learning in Process Optimization II / 148

Machine Learning-based Scrap Characterization for Process Optimization in Electric Arc Furnaces

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Scrap characteristics significantly influence the performance of the melting process in the Electric Arc Furnace (EAF). Along with other charged materials, scrap accounts for significant production costs. Hence, marginal process improvements can yield significant economic gains. However, the inherent heterogeneity of charged materials and the lack of elemental composition data on scrap properties currently act as primary constraints on scrap-mix optimization. To address this, the **MultiSensEAF** project was initiated with model-based scrap characterization as a core objective, leveraging both existing operational data and modern off-the-shelf sensors.

This study develops a comprehensive scrap characterization model using a multi-modal data approach. The primary data sources include high-fidelity operational and scrap-mix records provided by **Georgsmarienhütte (GMH) GmbH**. These datasets are integrated with Optical Emission Spectroscopy (OES) sensor data delivered by the **LUXMET** system installed at the GMH facility. To process this high-dimensional dataset, rigorous data exploration and feature engineering were conducted to identify the most influential scrap properties and their relationship to key operational parameters. Subsequently, various machine learning architectures, including multivariate regression, artificial neural networks, and random forests, were implemented to realize a robust statistical characterization model. A significant innovation in this research is the exploration of auto-adaptation for model parameters. By utilizing historical process data in conjunction with OES-based sensor data, the model can dynamically adjust its own parameters.

In conclusion, this study demonstrates the enhanced capabilities of integrated multi-sensor systems in developing predictive models for scrap characterization. The findings provide furnace operators with critical real-time insights into expected meltdown behavior, reducing uncertainty during the meltdown phase. Furthermore, the results indicate how estimated scrap properties can be utilized for advanced process control and the continuous monitoring of scrap quality, marking a significant step in the digitalization of EAF steelmaking.

Speaker Country:

India

Speaker Company/University:

IOB RWTH Aachen

Energy Efficiency and Consumption Reduction / **149**

Inert Gas Stirring in Electric Arc Furnaces: Metallurgical Benefits with a focus on medium- and high-alloyed steelmaking.

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Minimum conversion cost of alloyed steel production in the electric arc furnace require optimum mixing of the molten metal during melting and refining. Improved heat transfer accelerates the melting of larger scrap pieces for time and energy savings. Homogeneous distribution of alloy elements and carbon in the melt decreases the unwanted oxidation of alloys, e.g. Chromium for better metal yield and slag characteristics.
Inert gas stirring is an established method for improving process control, energy efficiency, metal yield, melting time, and metallurgical performance in EAF steelmaking areas such as oxygen control and dephosphorisation. To support these benefits and meet the increasing demands of larger EAFs in integrated steel plants, the portfolio of purging plugs has been expanded to meet the higher flow rates. The improvements in EAF process efficiency and metallurgy achieved with inert gas stirring are presented in industrial case studies.

Speaker Country:

Austria

Speaker Company/University:

RHI Magnesita

Slag control and refractories II / **150**

Effect of Al2O3 on structure and viscosity of EAF slag system

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Slag rheology is one of the important parameters in Electric Arc Furnace (EAF) steelmaking, as it significantly impacts process stability, energy efficiency, and the degradation of refractory materials, with its behavior strongly determined by the composition of the slag. The aim of this research is to understand the influence of Al_2O_3 on the structure and properties of EAF slag, thereby facilitating the transition towards hydrogen-based Direct Reduced Iron (DRI) and EAF steelmaking route. A slag system comprising $CaO–SiO_2–MgO–Al_2O_3–FetO$, characterized by a basicity ratio (CaO/SiO_2) of 2 and containing 30 wt% FeO, was formulated based on literature survey and thermodynamic analyses, in that way reflecting typical conditions of EAF steel slag. The content of Al_2O_3 was varied within the range of 5 to 12.5 wt%, while the saturation level of MgO (~5.8 wt%) and the melting temperatures were established through phase diagram analysis and equilibrium calculations. Synthetic slag samples were synthesized from reagent-grade oxides powder. The mixture was melted in a Tammann furnace at temperature ranging from 1517-1600 ℃, which elevated by 100 ℃ above the calculated melting point of each composition, followed by a holding period of 60 minutes to ensure uniformity prior to quenching via water-granulation. The quenched slag samples underwent characterization through X-ray Diffraction (XRD), Raman spectroscopy, Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS), and high temperature rheometer. The XRD analysis indicated that all examined samples displayed semi-amorphous characteristics alongside crystalline phases of MgO, α'-Ca_2SiO_4, and spinel. The Raman spectra evidenced prominent vibrational bands associated with Fe-O band within the slag matrix, with less Si-O band due to high basicity ratio. The combined XRD and Raman analyses provide a structural basis for correlating phase assemblage with high-temperature rheological behavior, which will be evaluated in subsequent viscosity measurements.

Speaker Country:

Indonesia

Speaker Company/University:

Luleå University of Technology

Slag control and refractories II / 151

More dynamic carbon injection: a novel approach for slag foaming control in EAF steelmaking with continuous charge feeding

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Direct Reduced Iron (DRI) is increasingly utilised as an alternative metallic charge in electric arc furnace (EAF) steelmaking for flat product manufacturing, due to stringent quality standards required for these steel grades. It is also being adopted in long product production, where scrap availability is often a bottleneck.
DRI quality fluctuations require continuous adjustments to the melting process. Currently, manual control largely remains the norm for the EAF process in most continuously fed production units.
Contrary to common belief, flat bath operation is more difficult to automate than batch process. It requires skilled personnel and prevents the possibility of applying a fully reproducible standard melting profile. Here is where most of the state-of-the-art schedulers are failing.
DRI is fed at a high rate. The energy required for melting is largely determined by the quality of the feedstock, particularly factors such as total iron, metallization, gangue, and carbon content. Physical

properties of the iron ore pellets, such as grain size distribution and the proportion of fines, significantly impact EAF performance beyond the reduction process itself.
Variations in these properties directly affect both energy consumption and furnace productivity. Even small changes in energy requirements can significantly impact melting behaviour, potentially causing unmolten material to accumulate and disrupting process management—occasionally resulting in unexpected reactions or equipment failures.
How to help operators to anticipate and contain those variances, adapting the process variables? How to standardize operations reducing the standard deviation of the key process indicators?
This paper describes how MORE technology and process expertise can improve operations. A controller works collaboratively with operators to optimise process efficiency, dynamically adjusting chemical package set points to automatically regulate foaming slag arc coverage and maximise energy input efficiency.
A process supervisor agent detects drifts and adjusts variables automatically when possible, reducing the need for continuous manual intervention by the operator. The operator assistant agent offers targeted suggestions, supporting the operator's role in deciding the melting strategy.
The application to their EAF in a long-term cooperation with EZDK flat division will be described, analysing the achieved results and improvements.

Speaker Country:

Italy

Speaker Company/University:

More Srl

Ongoing Research in Electric Steelmaking II / 152

Recent research, planned equipment upgrades and future work at the pilot EAF at RWTH Aachen University

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Several European steelmakers currently plan to transform integrated steel mills based on the BF-BOF route towards the DRI/HBI-EAF/ESF routes of steelmaking. This planned transformation goes hand in hand with the need to optimise the new process routes in order to produce the same high-quality products on these different and, for the steelworks concerned, new process routes.

The optimization of the EAF process in general is furthermore driven by increasing demands on sustainability and efficiency of the melting process. Alternative fuels, input materials like DRI or recycled materials as well as comprehensive process monitoring and control strategies are aiming to minimize the ecological footprint and increasing the circularity of EAF steelmaking. On the other hand, due to the extreme environment within the EAF, continuous measurement is quite difficult or even impossible for many relevant process parameters.

The application of pilot-scale testing can provide valuable inside through a more controlled or simply cheaper investigation of new equipment concepts, input materials or operating strategies. The 250 kg pilot-scale EAF at RWTH Aachen University was previously for example applied to investigate the use of biomass and agglomerated steelmaking residues in EAF steelmaking. Recently, the furnace was employed to test the substitution of natural gas by hydrogen in downscaled EAF burners with a main focus on hydrogen pickup of the steel melt.

To address the needs of future research work regarding the sustainable production of iron and steel, the furnace in the near future will be upgraded to improve general availability but also to add new equipment for continuous feeding of materials into the furnace during operation and improved sample taking. Furthermore, the furnace infrastructure like water cooling circuits and off gas treatment will be updated and improved as well as equiped with additional measurement points.

The uprades of the pilot EAF will open new possibilities for future research at RWTH Aachen University. It will be possible to investigate not only the scrap-based EAF steelmaking like before but also DRI/HBI-based steelmaking with continuous feeding of material. Furthermore, the furnace then can also be operated in a smelter/OSBF mode and will be equiped to handle reducing atmosphere and the related off gases which might also occur during carburisation trials when melting hydrogen reduced DRI/HBI either in EAF or OSBF mode.

Speaker Country:

Germany

Speaker Company/University:

RWTH Aachen University

New and emergent ironmaking Technologies II / 153

Techno-Economic Assessment of H_2-DRI and NG-DRI-CCS Processes for Low-Emission Iron Production

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The decarbonization of the iron and steel industry, responsible for approximately 7% of global energy-related CO2 emissions, represents a critical challenge due to its high energy demand and the intrinsic characteristics of the processes, making it strongly dependent on fossil fuels. Hydrogen-based direct reduced iron (H2-DRI) has gained increasing attention and is currently considered one of the most promising options for zero-emission iron production. Natural gas-based DRI plants equipped with carbon capture and storage (NG-DRI-CCS) also represent a competitive option, especially in areas with nascent CO2 infrastructure or limited access to renewable energy sources. The parallel development of CCS clusters and the continuous decline in renewable energy costs suggest that both pathways could play a complementary role in ironmaking decarbonization. This work provides a techno-economic assessment of low-emission DRI configurations based on CCS, electrification, and hydrogen.

The analysis is based on Aspen Plus® process simulations for a plant capacity of 2 MtDRI/y to derive mass, energy, and CO2 balances. The reference case is the Energiron Zero Reformer (ZR) process. In addition to the conventional configuration employing a combustion-based process gas heater, electrification of the gas heater is considered. Three CO2 capture options: (i) selective capture of the CO2 stream from the reducing gas recycle, (ii) full capture, which also includes post-combustion capture from the gas heater flue gas, and (iii) pre-combustion capture via water-gas shift reactor and CO2 removal. Two hydrogen-based cases are considered, which rely either on high-temperature electrolysis (HTE), with a Solid Oxide Electrolysis Cell (SOEC) system thermally integrated within the plant, or low-temperature electrolysis (LTE).
Techno-economic assumptions include a 25-year lifetime, an 8% discount rate, and cost assumptions

consistent with the recent literature. A sensitivity analysis explores how variations in energy costs may impact the optimal configuration.

Results indicate a cost of CO2 avoidance of 70-150 €/tCO2 for CCS configurations, largely dependent on the cost of natural gas and of CO2 transport and storage. The cost of CO2 avoidance for H2-DRI ranges from 270 to 560 €/tCO2 in the HTE case and from 470 to 890 €/tCO2 in the LTE case, for electricity prices between 60 and 100 €/MWh. An analysis of the economically optimal configuration as a function of energy prices shows that NG-based solutions equipped with CCS remain preferable across a wide range of conditions, while hydrogen-based options become competitive only when the electricity-to-natural-gas price ratio falls below approximately 0.75, or for premium markets.

Speaker Country:

Italy

Speaker Company/University:

Politecnico d Milano

Use of alternative iron sources / 154

EAF - Trials with Scrap and solid iron in a 6 tonnes pilot furnace

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Tata Steel Netherlands (TSN), aims to reduce the CO2 emission by 40% and enhance circularity by increasing the scrap usage to 30% by 2030. These targets will be achieved by replacement of one blast furnace with an Electric Arc Furnace (EAF) which utilise Direct reduced iron (DRI) and scrap as charge material.Increasing scrap usage in EAF steelmaking is essential for enhancing circularity and reducing CO_2 emissions. However, recycling scrap introduces tramp and residual elements (TREs) such as Cr, Cu, Mo, Ni, Mn, P, S, and N, which pose challenges for maintaining steel quality. Therefore the type and proportion of input charge materials are crucial in controlling the TREs in the future EAF operation.

This study investigates the distribution of TREs among steel, slag, and fume dust during Electric Arc Furnace (EAF) processing, based on trials conducted in a 6-tonne pilot EAF at the Materials Processing Institute. It also compares the effect of using solid pig iron sourced from Blast furnace (BF) and Hisarna process as part of the charge material on refining performance and foaming behaviour in the EAF.

Two melts were performed with solid iron (either sourced from BF or Hisarna process) and clean scrap to assess refining with different starting carbon levels, tramp element dilution, and slag behavior. Results highlight the influence of initial melt chemistry and operating conditions—such as carbon content, oxygen blowing, and slag basicity—on refining reactions (de-C, de-P, de-S, de-N) and slag evolution. High carbon levels in the melt promoted nitrogen removal via CO bubble formation, while low silicon and manganese were critical for effective decarburization. Further the behaviour of nitrogen refining and its relation with decarburisation and surface active elements like sulphur concentration has been analysed through a simplified kinetic model.

Phosphorus removal was observed to be limited by low slag basicity and FeO content. The lower C content and the higher oxygen levels, in the steel, were observed to contribute to the removal of S. Tramp elements largely remained in the steel, besides Cr that partially oxidized to the slag phase. Slag composition varied significantly with oxygen blowing, affecting FeO and P_2O_5 levels

and foaming behavior. These findings provide insights into optimizing future EAF operations for improved control of TREs and refining efficiency.

Speaker Country:

Netherlands

Speaker Company/University:

Tata Steel Europe

Poster session / 155

Mitigation of Copper Redeposition in Acid Pickling of EAF Flat Steels through Bath Chemistry Control

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One of the major challenges in scrap-based steel production is the retention of residual elements within the steel matrix, among which copper (Cu) is particularly critical. The inability to remove copper during steelmaking not only degrades mechanical and surface properties, but also causes significant operational problems in downstream processing stages.
Following hot rolling, oxide scale formed on the steel surface is removed by (HCl) acid pickling. During the pickling of flat steel coils produced via the electric arc furnace (EAF) route, copper present in the steel may dissolve into the acid solution. As copper accumulates in the pickling bath, it can subsequently redeposit onto the steel surface, leading to copper-plated surface layers. This phenomenon adversely affects surface quality and represents a serious concern for subsequent processes such as coating and forming.
In this study, the influence of Cu, Fe^{2+}, Fe^{3+} ion concentrations and inhibitor content in the acid pickling bath on copper deposition behavior was systematically investigated. Pickling baths with varying concentrations of Cu, Fe^{2+}, Fe^{3+} and inhibitor were prepared. C67 grade high-carbon steel was selected as the substrate material in order to clearly observe copper deposition tendencies.
During the experiments, Cu and total Fe were quantified by ICP analysis, while Fe^{2+} concentrations were determined by chemical titration and Fe^{3+} levels were calculated by difference. The redox potential of the acid bath was measured by the open circuit potential (OCP) method using a platinum working electrode and an Ag/AgCl reference electrode with a Gamry electrochemical measurement system. In addition, the effect of copper deposition on surface characteristics was evaluated through contact angle measurements to assess changes in wettability.
The results showed that copper deposition on steel surfaces is strongly governed by the redox state of the pickling bath, particularly the Fe^{3+}/Fe^{2+} ratio and overall redox potential. Higher Cu ion concentrations and more oxidizing bath conditions promoted copper redeposition, whereas appropriate inhibitor additions significantly suppressed this behavior. Copper-plated surfaces exhibited noticeable changes in wettability, indicating potential negative impacts on downstream coating and forming operations. These findings emphasize the importance of effective pickling bath chemistry control to mitigate copper-related surface defects in scrap-based flat steel production.

Speaker Country:

Turkey

Speaker Company/University:

Borçelik Steel Industry and Trade Co., Inc.

Ongoing Research in Electric Steelmaking I / 156

Sustainable steelmaking route for mitigation of CO2 emissions: Transition from blast furnace (BF) to electric smelting furnace (ESF)

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It has been known that approx. 7% emissions of CO2 arises from the steel industry sector. Hence, many steel companies are trying to develop the electric arc furnace (EAF) and/or electric smelting furnace (ESF) steelmaking processes instead of blast furnace (BF) and basic oxygen furnace (BOF) integrated routes by employing high amounts of hydrogen gas direct-reduced iron (H2-DRI) to mitigate CO2 emissions. The high-grade iron ores (Fe>68%) are economically used in EAF, whereas low-grade iron ores (Fe<65%) are targeted to be used in ESF. The integrated steel mills have focused on the ESF process by keeping conventional BOF to produce high-end quality products. The H2-DRI will be charged in ESF in conjunction with fluxes and carbon sources, producing hot metal. Using solid carbon alone as a reductant, FeO reduction proceeded through three distinct stages: incubation, steady state, and degradation, forming a characteristic sigmoidal curve. The carbon requirement for complete FeO reduction and at least 3wt% carbon in hot metal (HM) was calculated as 66 kg-carbon/ton-HM. Introducing a hot heel with dissolved carbon accelerated FeO reduction, lowering the FeO concentration to approximately 3wt% in the slag and producing hot metal with 2.8wt% C. Also, it was confirmed that Si transfer from slag to molten iron under ESF conditions occurs through the SiO2 reduction reaction, which produces SiO gas at the slag/metal interface, and the Si pick-up reaction, in which the SiO gas reacts with carbon in the molten iron. We performed a kinetic analysis to evaluate how temperature, slag basicity, and sulfur content in hot metal influence the SiO2 reduction and Si pick-up rates at the slag/metal interface. The current study provides fundamental data for optimizing slag design to achieve rapid FeO reduction, carburization as well as silicon control in ESF.

Speaker Country:

Korea South

Speaker Company/University:

Hanyang University

Recycling, circular economy and reduction of environmental impact in steelmaking I / 157

Quantification and Mitigation of Direct CO2 Emissions EAF Steelmaking

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Electric Arc Furnace (EAF) steelmaking generates CO_2 emissions from both direct process-related sources and indirect electricity consumption. While indirect emissions associated with grid electricity dominate overall emissions, direct process emissions—primarily from carbon additions used for slag foaming and refining—remain a significant and addressable source.

This paper will quantify direct CO_2 emissions from EAF steelmaking in Europe and evaluate practical strategies to reduce or eliminate these emissions through improved process control and alternative

operating practices. The potential impact of these strategies includes substantial reductions in carbon consumption and associated CO_2 emissions, representing significant economic value for the European steel industry through reduced material usage and carbon compliance costs.

Speaker Country:

Canada

Speaker Company/University:

Tallman Technologies

Slag control and refractories I / 158

Kinetic Study and Mechanism of SiO2 Reduction and Si Pick-up Reactions under Electric Smelting Furnace Conditions

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The hydrogen reduction iron- and steelmaking route is attracting global attention as an eco-friendly process for reducing carbon dioxide (CO2) emissions. It produces hot metal by melting hydrogen-based direct-reduced iron (H2-DRI) in an electric smelting furnace (ESF). In conventional blast furnace (BF) processes, the Si content of the hot metal is used as an indicator of hot metal quality and BF operating conditions and can be used to predict the impact on subsequent converter steelmaking processes. Similarly, Si content in hot metal is believed to be an important parameter in ESF operation. Therefore, in the present study, we confirmed that Si transfer from slag to molten iron under ESF conditions occurs through the SiO2 reduction reaction, which produces SiO gas at the slag/metal interface, and the Si pick-up reaction, in which the SiO gas reacts with carbon in the molten iron. We also conducted a kinetic analysis to evaluate how temperature, initial slag basicity, and sulfur content in hot metal influence the SiO2 reduction and Si pick-up rates at the slag/metal interface. The SiO2 reduction reaction exhibited a maximum reduction rate within an appropriate temperature range, and the reduction rate increased with decreasing slag basicity. The rate of the SiO2 reduction reaction is affected by the stability of the gas layer at the slag/metal interface, and an unstable gas layer accelerates the SiO2 reduction rate. The Si pick-up reaction rate increased with increasing temperature or decreasing slag basicity, and the activation energy for this reaction was 238.3 kJ/mol. Increasing the [S] content in hot metal, the SiO2 reduction rate and Si pick-up rate decreased and then increased again due to surface coverage effect and activity of CaS in the slag. The present study provides a systematic understanding of the reactions occurring at the slag/metal interface during the electric smelting furnace process.

Speaker Country:

Korea South

Speaker Company/University:

Hanyang University

Process Control and Quality Improvement / 159

Effect of Bottom-Blowing on Nitrogen Removal Kinetics in Electric Arc Furnace (EAF) Conditions

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Nitrogen is one of the most influential interstitial elements in steel, as it substantially alters mechanical properties through solid-solution strengthening. While elevated nitrogen levels enhance tensile and yield strengths, it simultaneously reduces elongation and promotes strain aging, thereby degrading formability. However, in the Electric Arc Furnace (EAF) process, nitrogen from the atmosphere dissolves into the molten steel during melting. Due to these challenges, nitrogen control is typically performed during secondary refining processes such as Vacuum Degassing (VD) and Ruhrstahl-Heraeus (RH) degasser. Consequently, reliance on these secondary refining steps increases process time and cost, thereby highlighting the need for methods capable of achieving nitrogen control directly within the EAF. In this context, recent studies have focused on utilizing bottom-blowing technology in the EAF process to improve nitrogen removal from molten steel. Furthermore, with the increasing adoption of hydrogen-reduced DRI (H2-DRI) in the EAF process as part of the transition to environmentally friendly steelmaking, new challenges in nitrogen removal are emerging. H2-DRI has an extremely low carbon content, leading to insufficient CO gas generation during melting. In traditional EAF processes, CO gas, generated from the reaction between FeO and carbon, plays a crucial role in promoting nitrogen removal. However, as the usage of H2-DRI increases, the lack of a carbon source reduces CO gas formation, thus diminishing the nitrogen removal efficiency. Therefore, the present study aims to investigate the efficiency of nitrogen removal through bottom-blowing in EAF operating conditions. In particular, the effects of injecting Ar/CO2/CO gas mixtures and varying carbon content in molten steel on nitrogen removal kinetics were examined.

Speaker Country:

Korea South

Speaker Company/University:

Hanyang Univerisity

Circularity and by-product management in the steel industry / 160

Development of Sustainable Silica-Alumina Insulating Refractories for Coke Oven Applications

Authors: Alberto Cardellini[1]; Elisabetta Arato[2]; Fabrizio Strobino[1]; Maia Clericuzio[2]

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The iron and steel industry is widely recognized as a hard-to-abate sector due to its high energy demand and reliance on high-temperature processes. While significant attention is often devoted to primary steelmaking routes, secondary systems such as coke ovens also play a crucial role in overall energy efficiency and environmental performance. In this context, the optimization of refractory materials represents a key opportunity to reduce heat losses, improve process efficiency, and enhance sustainability.

This research project focuses on the development of sustainable insulating refractories specifically

designed for coke oven applications. In collaboration with Paul Wurth Italia S.p.A. (SMS group), silica–alumina insulating bricks are produced using locally available raw materials and biomass-derived additives, including sawdust, rice husk, fly ash, and biochar. These secondary materials act as pore-forming agents while simultaneously serving as alternative sources of silica and alumina, promoting lightweight structures and supporting material circularity through the valorization of industrial and agricultural by-products.
The objective is to develop insulating refractory bricks with properties comparable to those of conventional commercial products, while reducing reliance on primary raw materials. Different formulations are investigated, with particular emphasis on the SiO2/Al2O3 ratio, leading to the development of various classes of insulating bricks tailored to specific thermal and mechanical requirements. Target performance includes thermal conductivity values in the range of 0.2-0.3 W/m·K at 800 ℃, cold crushing strength around 1.5 MPa, and bulk density between 0.45 and 0.8 g/cm3. These parameters are selected to ensure adequate insulation efficiency, structural stability, and resistance to thermal stresses under coke oven operating conditions.
By integrating alternative raw materials into refractory design, this work highlights the potential of sustainable material solutions to improve energy efficiency and resource utilization in coke oven operations. Future developments will include a comprehensive environmental assessment to further quantify the potential benefits of the proposed materials within the steelmaking value chain.

Speaker Country:

Italy

Speaker Company/University:

Università di Genova

Automation and Digitalization in Electric Steelmaking III / 161

Measuring Technologies for DRI-fed Electric Arc Furnaces

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We present a design and the results of several trials of a Radar level probe. This probe measures the slag level during the EAF operation. The measured level can be compared to the model result of the slag foaming indication. The trend of the slag level indicates the end-of-batch by exactly identifying the rapid increase of the slag level. By accurately measuring the foaming level, batch to batch time and power consumption during melting can be reduced.

We also present a metallization degree sensor that can monitor the quality of the DRI or HBI which are fed into the EAF. The metallization degree is known to fluctuate, and a reduced value has an impact on the slag quality and on the amount of carbon required. The sensor can be used to check material periodically, or, on-line in a continuous feed. Tests show that the quantities of iron and carbide are both assessed with an accuracy better than 1%wt, and that both DRI pellets or HBI briquettes can be measured. Various factors such as the voidage, pellet or briquette shape, or slag composition only have a marginal impact on the sensor's accuracy.

The values of both sensors also help to operate a Hot Heel level model. The slag foaming behavior leads to knowledge about the slag amount. The exact slag level is known before and after steel tapping.

Speaker Country:

Luxembourg

Speaker Company/University:

Marvin Schmidt

Ladle metallurgy and slag control / 162

Assessment of dephosphoration and desulphurizing capacity of the slag as a function of the firing conditions of the lime

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Optimizing the removal of impurities like phosphorus and sulphur is crucial for producing high-quality steel and enhancing process efficiency. This study systematically assesses how the firing conditions of lime —a primary slag-forming agent—directly influence the dephosphorization and desulphurization capacity of metallurgical slags. A series of controlled laboratory-scale equilibrium experiments were performed to determine the partition ratios of sulphur between hot metal and slag, and of phosphorus between steel and slag. The experimental design utilized slags of identical target chemical composition, but varied the lime component based on its calcination history. Limes produced under different firing temperatures and residence times were characterized for key properties such as reactivity, specific surface area, and crystalline structure.
The results demonstrate a clear and quantifiable dependency of the slag's refining performance on the provenance of the lime. Variations in lime reactivity significantly altered the kinetics and thermodynamic equilibrium of the impurity-removal reactions. Specifically, lime with higher reactivity and tailored microstructure, achieved through optimized firing, promoted more efficient assimilation into the slag, leading to improved sulphide and phosphate capacities. Consequently, the final partition coefficients for both sulphur and phosphorus were markedly enhanced, confirming that lime quality is a critical, yet often overlooked, process variable.
This investigation provides actionable insights for steel producers, emphasizing that precise control over lime manufacturing parameters is not merely a quality concern for the refractory industry, but a powerful lever for metallurgical control. By specifying lime characteristics, plants can achieve deeper impurity removal, reduce flux consumption, and improve slag management, contributing to both economic and environmental sustainability in steelmaking operations.

Speaker Country:

Italy

Speaker Company/University:

University

Recycling, circular economy and reduction of environmental impact in steelmaking II / 163

Assessment of the natural absorption of CO2 performed by electric steelmaking slag

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This study aims to evaluate the natural CO2 absorption potential of steelmaking slag, focusing on both black (EAF) and white (LF) slag generated during steel production. Such slags contain significant amounts of calcium and magnesium compounds capable of reacting with atmospheric CO2 through carbonation, forming stable carbonates and thereby enabling permanent carbon sequestration. Representative samples of black and white slag were monitored to assess their physicochemical properties, mineral composition, and carbonation behaviour under natural environmental conditions over time. The investigation seeks to characterize and quantify the tendency and rate of CO2 uptake for each slag type, highlighting differences in carbonation efficiency. Preliminary findings contribute to understanding the role of steel slag as potential carbon sinks within the steel industry, supporting sustainability goals. Furthermore, the study discusses factors influencing carbonation, such as particle size, exposure time, and ambient conditions, providing insights into optimizing slag management to enhance CO2 sequestration. This research represents a step forward in incorporating natural carbonation processes of steelmaking by-products into carbon accounting frameworks and promoting their beneficial reuse in climate change mitigation strategies.

Speaker Country:

Italy

Speaker Company/University:

University

Automation and Digitalization in Electric Steelmaking III / 164

Driving Innovation in Steel Production: Huisman's entry into the Process Crane Market

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For over 90 years, Huisman has been active in heavy offshore lifting, engineering cranes with capacities up to 10,000 tons.
Today, we are adding a new chapter—one that aligns with the steel industry's bold transformation toward low-emission steel production. As electric arc furnaces and hydrogen-based DRI technologies reshape steelmaking, we asked ourselves: how can lifting technology contribute to this change?

Our answer: We used our experience in lightweight crane design to develop a new serie of process cranes ranging from 130 ton slab handling cranes up to 700 ton teeming and charging cranes for the

steel plants of the (near) future.
The new crane designs achieve an average weight reduction of 20–30%, enabling lighter factory structures and foundations, which can result in reduced costs and a smaller CO_2 footprint.

With the first two cranes already sold to a European steel plant in 2025, it showcases that progress is possible. We are proud to contribute with these technologies to sustainable steelmaking and shape the future of industrial lifting.
Join us as we redefine crane technology for the next generation of steel plants.

Speaker Country:

Netherlands

Speaker Company/University:

Arthur de Mul - Huisman Equipment

Renewable gases and CO2 mitigation in steel industry I / 165

Assessment of Biochar Production and Integration into HIsarna Ironmaking

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HIsarna ironmaking is a breakthrough smelting-reduction technology with the potential to reduce CO_2 emissions by about 50% when operated with coal. However, further decarbonisation of the process requires replacing fossil carbon with sustainable alternatives. In this context, biochar derived from woody biomass emerges as a promising renewable carbon carrier, provided it can be produced economically within the plant boundary. This study evaluates biochar integration to the HIsarna process operations from the perspective of raw material consumption, unit wise energy requirements, and by-product utilisation using a flowsheet modelling approach. In the present study, biochar is produced by slow pyrolysis of pinewood biomass with moisture contents of 33% and 10%, resulting in yields of approximately 35% biochar, 50% bio-oil, and 15% biogas. The analysis explicitly accounts for energy demand associated with drying, pyrolysis, and grinding, and for the utilisation of bio-oil and biogas either through internal combustion or through a combined strategy of bio-oil selling and biogas burning. Four cases are analysed by combining two biomass feedstocks (raw pinewood biomass and torrefied biomass) with two heating options for the pyrolysis unit (natural gas fired heating and electric heating). The flowsheet modelling is designed to supply the biochar required for a HIsarna plant producing 1 million tonnes of hot metal per year. Mass and energy balances are established for the integrated system, followed by a techno-economic evaluation of the net biochar supply cost to HIsarna process. The analysis is carried out assuming representative baseline values for biomass price, electricity price, and carbon credits. Under these base-case conditions, Case1, the bio-oil and biogas burning pathway delivers a net energy surplus of about 8 GJ/t to 13 GJ/t biochar produced, with the resulting net biochar supply cost showing a strong dependence on biomass type and heating option. In contrast, Case 2, the bio-oil selling with biogas burning pathway reduces the net energy surplus to approximately 1 GJ/t to 5 GJ/t biochar produced but improves the net biochar supply cost compared to Case 1. Sensitivity analysis indicates that increasing electricity prices penalise electrically heated configurations most and shifts the preference toward natural gas based pyrolysis.

Speaker Country:

Netherlands

Speaker Company/University:

TU Delft

Ladle metallurgy and slag control / 166

The Study of Different Ca Cored Wires on Calcium Treatment Process

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Calcium (Ca) treatment is widely used in ladle metallurgy to modify alumina-based inclusions and improve steel cleanliness. The effectiveness of this process largely depends on the type of Ca-cored wires employed and the refining conditions, which influences dissolution behavior, calcium recovery and ultimately inclusion modification. This study examines two commonly used wire types-pure Ca and CaSi under various refining scenarios in the ladle metallurgy process. Their dissolution behavior and interactions with steel and slag are compared using thermodynamic tools, while their impact on inclusion modification is evaluated based on plant trial data.

Speaker Country:

Canada

Speaker Company/University:

Kezhuan Gu, Ilia Ushakov, Kagan Keler

Energy Efficiency and Consumption Reduction / 167

Predicting EAF melt performance by using online off-gas data

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Monitoring off gas of an EAF allows to predict the decarburization process and hence the melt performance of the tap during the melting process. Using the off-gas data events such as scrap cave-ins, overdrafting and varying scrap moisture can be visualized in real time and hence predictions can be made about necessary changes in O2 lancing, electrode power as well as carbon injection. The paper describes the off-gas measurement method and gives sample data of EAF processes where the off-gas measurement is installed.

Speaker Country:

Germany

Speaker Company/University:

Hans Georg Conrads

Poster session / 168

High-Cleanliness Production of Crankshaft Steel through Optimization of Slag Composition

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Based on the Ion–Molecule Coexistence Theory (IMCT) and the steel–slag equilibrium theory, this study establishes a thermodynamic equilibrium calculation model for the high-cleanliness production of crankshaft steel. Systematic calculations were performed to determine the rational distribution range of SiO2 in the slag, as well as the recommended CaO/Al2O3 ratio. The variations in inclusion composition and population before and after slag optimization were then comparatively analyzed. The results indicate that, for the crankshaft steel investigated in this work, achieving a high level of cleanliness requires the aluminum content in steel to be no less than 0.008 wt%. Correspondingly, the SiO2 content in the slag should be maintained below 10 wt%, while—considering slag stability during refining—it should not fall below 5 wt%. Increasing the CaO/Al2O3 ratio effectively reduces the activity of SiO2, thereby mitigating its oxidizing effect on the molten steel. Furthermore, to ensure favorable slag formation behavior and efficient inclusion absorption, the slag composition should be adjusted as close as possible to the liquid phase region of the CaO–Al2O3–SiO2 ternary phase diagram. Through the optimization of slag composition and the coordinated design of Al and Si contents in steel, the cleanliness of crankshaft steel was significantly improved, with a pronounced reduction in both the number and the overall size of large inclusions.

Speaker Country:

China

Speaker Company/University:

University of Science and Technology Beijing

Poster session / 169

The Effect of Ce Content on NbC precipitate in S30432 Austenitic Heat-resistant Steel

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In order to improve the distribution of large-sized NbC aggregation in S30432 austenitic heat-resistant steel, this study systematically investigates the mechanism of modified inclusions with different Ce contents. First, the morphology, size, and distribution characteristics of NbC formed under solidification segregation were observed using SEM; further, the three-dimensional morphology of NbC precipitate was examined using a non-aqueous electrolysis method. Subsequently, the experimental analysis examined the heterogeneous nucleation of NbC by different oxide inclusions in the steel within the Ce content range of 0-0.1%. In addition, the nucleation efficiency of four types of oxide inclusions was verified through lattice mismatch calculations. Finally, the precipitation mechanism of Ce-containing inclusions was calculated using the FactSage 8.3 thermodynamic software. The results show that NbC, with sizes of several hundred micrometers, aggregates at the grain boundaries and cannot be eliminated by heat treatment; however, it can be uniformly dispersed through

heterogeneous nucleation by oxide inclusions. Among them, MnCr2O4, AlCeO3, and Ce2O3 can all act as the cores for heterogeneous nucleation; however, when the Ce content is below 0.05%, the single-type inclusions in the steel are Ce2SiO5, which cannot nucleate, while composite inclusions such as MnCr2O4 can nucleate but are too few in number to effectively disperse NbC. When the Ce content exceeds 0.03%, the Ce-containing oxide inclusions transform into AlCeO3; as the Ce content continues to increase to 0.05%, the type of oxide core is modified to Ce2O3. This type of inclusion has a high nucleation efficiency and is evenly distributed in the steel, which can effectively disperse NbC.

Speaker Country:

China

Speaker Company/University:

University of Science and Technology Beijing

Scrap management and quality improvement / 170

Process Intensification of EAF-A New Perspective with Plasma

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Against the backdrop of the steel industry's low-carbon transition, short-route production centered on the electric arc furnace (EAF) is attracting increasing attention because it can couple with renewable electricity and reduce CO_2 emissions substantially. However, current EAF operations face several challenges, when melting materials such as direct reduced iron (DRI), especially DRI from hydrogen reduction process, which contain high levels of oxides. As the share of DRI in the metallic charge continuously increase, higher demands are placed on heat utilization, energy distribution, and operational stability in EAF processing. The presence of high oxides content in DRI leads to low thermal conductivity of charging materials in EAF, heat transfer efficiency is often insufficient, leading to high furnace lid temperatures and low melting efficiency. This is especially problematic when higher proportions of DRI are used, as the heat transfer within the furnace becomes inadequate, resulting in uneven melting and affecting the temperature distribution and compositional homogeneity of the melt. These constraints may ultimately deteriorate productivity, increase energy consumption, and compromise endpoint consistency. To address the requirements of efficient, stable, and low-emission operation under high-DRI conditions, we propose a plasma-assisted EAF intensification route. Building upon conventional arc heating, a controllable high-temperature plasma jet/heat source is introduced to establish a coupled "arc–plasma–melt bath"intensification configuration. Owing to the high energy density and directional controllability of plasma, the proposed concept enables more concentrated and better-regulated heat input and promotes more effective heat penetration into the melt. Furthermore, plasma-assisted heating can significantly enhance the thermal conductivity of the charge, thereby facilitating faster heat transfer within the furnace and accelerating the melting process. In addition, the momentum delivered by the plasma jet enhances bath convection and interfacial renewal, thereby accelerating thermal equilibration and compositional mixing and creating more favorable transport conditions for melting and refining-related processes. By coordinating plasma operation with conventional process levers such as oxygen supply, carbon input, and stirring, the proposed approach aims to improve the electrical efficiency, thermal efficiency, as well as the process repeatability without requiring substantial changes to the main furnace architecture. This integrated intensification strategy is expected to mitigate operational fluctuations and reduce specific energy demand, thereby lowering indirect emissions associated with electricity consumption and supporting further decarbonization of EAF-based short routes. Overall,

plasma-assisted EAF processing offers a scalable solution to improve energy efficiency and emissions in DRI–EAF operations, supporting EAF innovation and green manufacturing.

Speaker Country:

China

Speaker Company/University:

University of Science and Technology Beijing

Ongoing Research in Electric Steelmaking I / 171

Preliminary Results on the Melting of Individual Hydrogen Direct Reduced Iron Pellets in a Laboratory-scale Electric Arc Furnace

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Steel industry is currently undergoing a significant transformation, driven by the need to reduce greenhouse gas emissions and move towards more sustainable production methods. Hydrogen-based direct reduction of iron (H-DRI) is a promising alternative to traditional carbon-based reduction methods. The integration of hydrogen-based reduction technologies with electric arc furnace (EAF) operations appears particularly promising for CO2-lean steelmaking from high-quality ore. Contemporary EAF processes already utiliseutilize recycled scrap and DRI as feedstocks, improving material efficiency. While the melting behaviour of conventional carbon-containing DRI pellets has been extensively, detailed information on the melting of H-DRI pellets remains limited.

This present work showcases preliminary results from melting individual H-DRI pellets (reduction degrees 33%, 43%, 68%, and 80%) in a laboratory-scale electric arc furnace. The melting process and arc behaviour are studied using in-situ monitoring tools, allowing the identification of characteristics related to melting behaviour and furnace parameters that affect the melting of individual H-DRI pellets.

This work provides a foundation for future experiments related to H-DRI pellets and laboratory-scale EAF and identified critical parameters for the development of its operating practices.

Keywords: electric arc furnace, direct reduced iron, melting

Speaker Country:

Finland

Speaker Company/University:

University of Oulu

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Coffee break

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Scrap-Based Steelmaking: Integrating AI, Life Cycle Assessment and Critical Raw Materials to Advance Circular Strategies

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High-performance forged components (e.g., steam-turbine shafts) demand tight control of microstructure and creep behaviour. In industrial development, however, parameter selection and qualification frequently involve iterative loops (trial batches, rework and occasional scrap), which translate into avoidable material and energy losses. AID4GREENEST project tackles this challenge by combining data-centric AI and physics-informed modelling to support earlier and more reliable decision-making across the steel value chain. Although simulation-based tools such as FE thermal modelling are currently well-established in forging companies, artificial intelligence has emerged as a natural progression to optimize product design. In this way, the trial and error approach can be minimized by selecting the most appropriate manufacturing parameters route to achieve the desired properties in the final product.

To understand the environmental impact of these innovations, an analysis of a non-optimized process is proposed as the basis of the study. The study includes a life cycle assessment (LCA) to assess the environmental footprint of manufacturing steam shafts from recycled steel, highlighting how existing residue streams at Reinosa Forgings & Castings are revalorized, contributing to the circular economy. The analysis initially follows a 'cradle-to-gate' approach, prioritizing processes such as EAF melting, refining, and casting, proposing scenarios to measure the impact of by-product revalorization. Primary data was collected directly from industrial operations, supplemented with secondary data from Ecoinvent v3.11, and modelled using Umberto 11.15.2. The assessment of environmental impacts was based on the production of one tonne of ingot as the functional unit. Initial results indicate that RFC's processes where residue streams are revalorized present a reduction on environmental impact of as much as 15% in comparison with processes performed elsewhere where these streams are disposed as waste.

As an added value for industrial decision-making, the LCA inventory is also screened from a Critical Raw Materials (CRM) perspective, identifying and tagging input streams that fall under the EU CRM framework. In the EAF route assessed, this includes materials associated with electrode consumption (graphite), CaF_2-based additions (fluorspar), and selected alloying-related inputs (e.g., Ni-, Mn- and V-bearing additions). This enables reporting, alongside conventional impact indicators, a simple "CRM intensity"per tonne of ingot and the scenario-driven change in CRM exposure when circular residue management and yield-related improvements are implemented. Finally, by utilizing the synergies of AI-tools, LCA, and CRM screening, the present study provides quantified evidence to support both environmental performance and reduced dependency on critical material supply chains.

Speaker Country:

Germany

Speaker Company/University:

Mary Osorio Baena/ EurA AG

Poster session / 174

A Front-Fixing Approach for Scrap Dissolution Modeling in EAF Steelmaking

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Describing scrap dissolution has become a topic of renewed interest due to the increasing significance of the electric arc furnace in global raw steel production, as well as the growing complexity introduced by charging mixtures of scrap, DRI, HBI, and hot metal. We present a physically based, computationally efficient dissolution model built on a front-fixing moving-boundary formulation. The model accounts for coupled heat and mass transfer at the solid-liquid interface and is validated against laboratory-scale experimental data. We discuss its potential application to EAF process analysis and optimization.

Speaker Country:

Austria

Speaker Company/University:

Montanuniversität Leoben