JOM, Vol. 74, No. 5, 2022
https://doi.org/10.1007/s11837-022-05253-9

Energy Efficiency and Low Carbon Footprint in Metals Processing

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According to the 2018 report of the Intergovernmental Panel on Climate Change (IPCC) on the impacts of global warming up to 1.5°C above pre-industrial levels, CO_2 emissions need to decline by about 45% by 2030 and reach net zero in 2050. In the 2019 pronouncement of the United Nations,[1] over 50 countries committed to carbon neutrality by 2050, and the decarbonization of metal production processes was identified as crucial to achieving the carbon neutrality goal.*

Metal production technologies are carbon and energy intensive, but it can be argued that the bulk of the carbon footprint of metal processes comes from energy sources and reductants. This is especially intensive in the iron and steel industries, where the heavy dependence on carbon sources for reductive smelting is a major contributor to high CO_2 emissions. As illustrated in Fig. 1, decarburizing industrial processes requires a convergence of an array of the following strategies:

(i) Improved energy efficiency in processes
(ii) Alternative reductants such as bioreductants and hydrogen
(iii) Capturing of carbon
(iv) Renewable energy sources

Improving process energy efficiency and capturing process carbon remain challenging and still require intensive study to scale-up and deploy enabling technologies.

Research and development efforts to take extractive metallurgy to the next level generally aim at (1) effective utilization of the energy content of feedstock, (2) minimization/elimination of carbon-based fuel consumption, (3) efficient environmental pollution control and the production of controlled gases as a side stream resources, e.g., as a feed stock for acid plants, and (4) near 100% extraction and recovery of the primary and minor metals from different feedstock. These efforts will eventually lead to creating adaptive and energy efficient metallurgical processes.

For the March 2022 issue, *JOM* Advisors of the Energy Committee, Recycling and Environmental Technologies Committee, and Process Technology and Modeling Committee of The Minerals, Metals & Materials Society organized a special topic with a focus on improved extractions and recoveries of the strategic metals, "Recovery of Rare Earth and Critical Metals from Unconventional Sources".[2] For this May issue, original research and review papers focusing on energy efficiency and low carbon footprint in the metals processing industries were invited and five papers were selected for publication after a peer review.

The first article in the list, "Electroreduction of Antimony Sulfide Enhanced by Nitrogen Bottom Blowing in Molten NaCl-KCl-Na_2S," by Zhu et al. proposes a novel nitrogen bottom-blowing method to enhance mass transfer in the molten salt electrolysis process, which also improves current efficiency and reduces electrolysis energy consumption. The authors have also investigated the effect of nitrogen agitation on the dissolution of Sb_2S_3 and Sb. According to their observation, nitrogen agitation

*Joseph Hamuyuni, Fiseha Tesfaye, Chukwunwike Iloeje, and Alexandra Anderson are Guest Editors from the following TMS technical committees: Energy; Recycling and Environmental Technologies; and Process Technology and Modeling. They coordinated the topic on Energy Efficiency and Low Carbon Footprint in Metals Processing in the May 2022 issue of JOM.

(Received February 28, 2022; accepted March 1, 2022; published online March 24, 2022)

can obviously accelerate the dissolution of Sb_2S_3. They reported the current efficiency of the cathode to be 92.76%, the energy consumption to be 1.78 kWh kg^{-1}, and the grade of crude antimony to be 98.5%. The overall electrolytic current efficiency improved by 19.87% and energy saving improved by 20.89% because of the nitrogen stirring. Additionally, authors suggest that appropriate flow rate of nitrogen to accelerate the removal of sulfur from the reactor avoids the formation of high-priced antimony compounds.

The second article, entitled "CO_2 Gasification of Densified Biomass: The Influence of K on Reaction Rate," by Kaffash and Tangstad examined the reactivity of metallurgical coke and densified charcoals. They designed experimental procedures to simulate conditions occurring in an industrial furnace of Mn-alloys production. To determine the catalytic effect of potassium, samples were impregnated using a gaseous impregnation technique with K_2CO_3, with concentration of up to 5 wt.% K. They reported that increasing potassium content led to an increase in the CO_2 reactivity of coke and charcoal. The CO_2 reactivities of the coke and densified charcoal were comparable when the maximum 5 wt.% K was applied.

The article entitled "Oscillating Currents Stabilize Aluminum Cells for Efficient, Low Carbon Production" by Mohammad et al. described a new invention for manufacturing aluminum while using 12% less heat and 4% less electricity. According to the authors, their invention works by thinning the high-resistance electrolyte layer through which electrical current must pass to liberate Al from dissolved aluminum oxide. This method could allow Al production at lower cost with less energy and smaller carbon footprint.

The article entitled "Thermal Degradation of Poly (Styrene-co-methyl Methacrylate) in the Presence of AlI3 Nanoadditive" by Bahadur et al. presented results of the study of the effect of AlI3 nanoadditive (NA) on the thermal degradation of poly (styrene-co-methyl methacrylate) PSCMMA. They produced the PSCMMA nanocomposites with the addition of AlI3 NA in an acetone common solvent by varying the added amount by up to 5 wt.%. Using thermo-analytical techniques (TGA, DTG, DTA), they determined the thermal degradation of PSCMMA with different concentrations of AlI3 NA. As a result, they reported that the thermal degradation temperature increased proportionally with increasing concentration of AlI3 NA, and the pure PSCMMA to burned five times faster than PSCMMA6 nanocomposite (which has 5 wt.% AlI3).

The fifth article, titled "Thermoeconomic Dyanamics of Orange Hydrogen Production, an Energy Matter," by Neelameggham et al. presents a detailed thermo-economics and -dynamics of energy-efficient orange hydrogen production. Their analysis revealed that a spectrum of costs in the production exists primarily from the energy conversion costs and economics of such energy conversions. The analytical results reported in the article suggest low-cost hydrogen production possibilities from hydrocarbons called 'orange' hydrogen, which is CO_2 free, along with the ease of making it from the ground using the present-day renewable energy technologies.

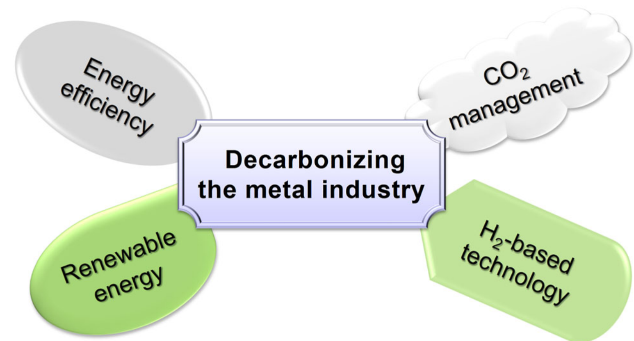

Fig. 1. A schematic diagram showing main components contributing to the decarburization of the metal industry.

The peer-reviewed papers in this special topic should be of interest to a broad readership including those considering a more sustainable production of metals such as Al and hydrogen for decarbonizing the metal-making industry. The titles of the articles published under this topic in the fourth issue of *JOM* this year (vol. 74, no. 5) are listed below and can be fully accessed via the journal's page at: https://link.springer.com/journal/11837/74/5/page/1.

- "Electroreduction of Antimony Sulfide Enhanced by Nitrogen Bottom Blowing in Molten NaCl-KCl-Na_2S" by Q. Zhu, J. Yang, C. Tang, T. Nan, R. Ding, and J. Liu
- "CO_2 Gasification of Densified Biomass: The Influence of K on Reaction Rate" by H. Kaffash and M. Tangstad
- "Oscillating Currents Stabilize Aluminum Cells for Efficient, Low Carbon Production" by I. Mohammad, M. Dupuis, P.D. Funkenbusch, and D.H. Kelley
- "Thermal Degradation of Poly (Styrene-co-methyl Methacrylate) in the Presence of AlI3 Nanoadditive" by A. Bahadur, S. Iqbal, H.O. Alsaab, N.S. Awwad, H.A. Ibrahium, F.H. Alshammari, N. Alwadai, and M.T. Alotaibi
- "Thermoeconomic-dynamics of Orange Hydrogen Production, an Energy Matter" by N. Neelameggham, G. Subramanian, and P. Kalamegham

ACKNOWLEDGEMENTS

Organizers of this topic would like to thank all authors and reviewers that have contributed to the successful publication of this special issue. We are convinced that your expertise has resulted in an excellent issue on this timely topic of *JOM*. The authors are also grateful to the Academy of Finland (decision number 311537) and the CircVol 6Aika project for financial support as part of the activities of the Johan Gadolin Process Chemistry Centre at Åbo Akademi University. We acknowledge support from UChicago Argonne LLC, Operator of Argonne National Laboratory ("Argonne"). Argonne National Laboratory's work was supported by the US Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), under contract DE-AC02-06CH11357. The US Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan.

Conflict of interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

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2. C.O. Iloeje, F. Tesfaye, A.E. Anderson, and J. Hamuyuni, *JOM*. https://doi.org/10.1007/s11837-022-05155-w (2022).