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Thermodynamic Modeling of Sustainable Non-Ferrous Metals Production: Part II

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Non-ferrous metals demand continue to increase globally as they are essential in variety of high-tech applications including those in the renewable energy sector. For example, the European manufacturing capacity of Li-ion batteries, which require a substantial amount of metals such as Ni and Co, is expected to grow by over 15 times than the current capacity by 2025; consequently, the consumption of valuable metals is expected to increase drastically. According to the World Bank Commodities Price Forecast presented in Fig. 1, prices of Sn, Ni, Cu, Zn and Pb are continue to increase since 2016 and are expected to keep rising until 2025. However, the current global lockdown and significant disruption in the commodities supply chain due to the COVID-19 pandemic may have short-term fallouts in the forecasted prices.

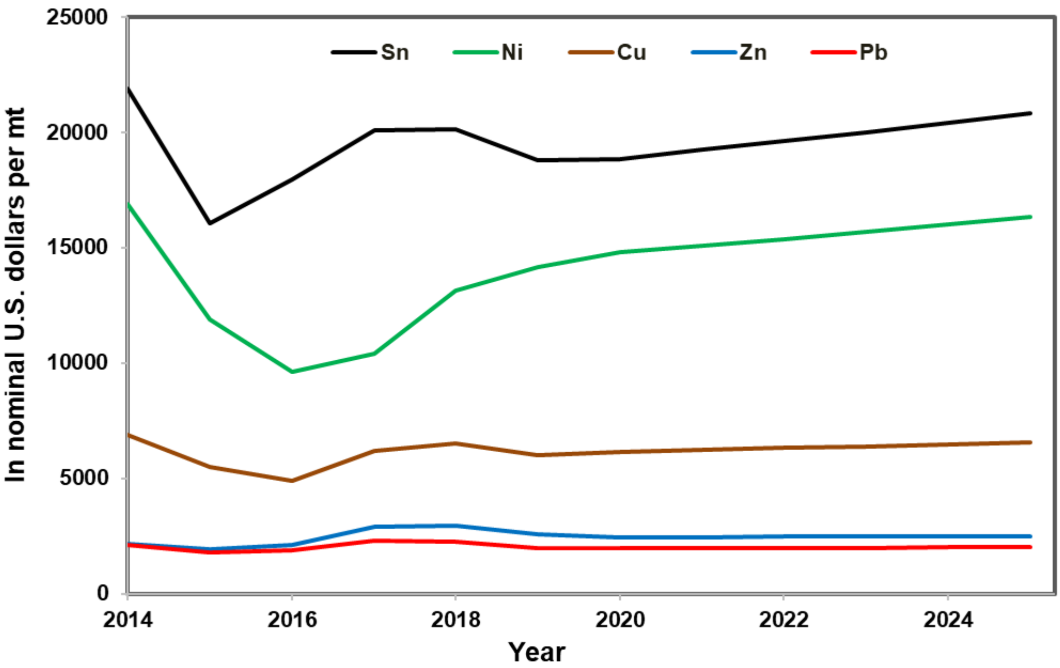

Fig. 1. Average prices for selected non-ferrous metals worldwide from 2014 to 2025. Data, including the World Bank Commodities Price Forecast between 2019 and 2025, was adapted from [1].

The global increase in the demand for the non-ferrous metals has also amplified their recovery from waste streams. In addition to promoting the recovery of resources from waste streams, emphasis is also placed on enabling the prevailing primary resources processing technologies to reduce environmental footprints and improve energy efficiency.

In 2020, among others topics, *JOM* advisors of the Recycling and Environmental Technologies and Process Technology and Modeling technical committees of TMS - The Minerals, Metals & Materials Society have organized special issues on “Cleaner Manufacturing of Critical Metals [2]” and “Thermodynamic Modeling of Sustainable Non-Ferrous Metals Production”. The later topic was divided into two parts. Part I that constituted articles with a focus on promoting improved and sustainable way of producing the platinum group metals (PGMs) and rare earth metals (REMs) from different sources was published in the July issue of *JOM* [3]. For Part II, the present issue, papers covering experimental investigations, thermodynamic modeling, metallurgical process optimization, resource efficiency and environmental issues, particularly those pertaining to non-ferrous metallurgical processes, were invited and five articles were approved for publication.

The papers in this issue are primarily devoted to the development of sustainable methods for producing various non-ferrous metals such as Cu, Sn, Pb, Au, etc. from different sources. The first paper “Combination of Pyrolysis and Physical Separation to Recover Copper and Tin from Waste Printed Circuit Boards” by Xun Wang proposed a combination of pyrolysis and physical separation to recover both metals and non-metals from waste printed circuit boards (WPCBs). Based on their experimental investigations, they have shown that up to 95% Cu and 86% Sn can be recovered from the WPCBs.

Two contributions investigated recovery of Pb from spent lead-acid batteries. The paper “Recycling of Spent Lead-Acid Battery for Lead Extraction with Sulfur Conservation” by Yun Li et al. proposed a cleaner lead-acid battery (LAB) recycling process via pyrometallurgical processing route. They have presented a method for lead extraction from LAB and control of excessive generation of SO_2. Boyi Xie et al. showed in their article entitled “Recovery of Lead from Spent Lead Paste by Pre-Desulfurization and Low-Temperature Reduction Smelting” that up to 93% Pb can be recovered from LAB through a process involving pre-desulfurization followed by low-temperature reduction smelting.

The last two papers in this issue presented phase equilibria and thermodynamic modelling of oxide systems in the non-ferrous metals production processes at high-temperatures. The paper “Phase Equilibrium Study of the CaO-SiO_2-MgO-Al_2O_3-TiO_2 System at 1300 °C and 1400 °C in Air” by Junjie Shi et al. presented new experimental phase equilibria data at high-temperatures that contribute to titanium containing resource processing. The data also updates the related thermodynamic databases for enabling the move towards digitalization of metallurgical processes. The last paper in this issue “Thermodynamic Modeling of the Na_2O-SiO_2-As_2O_5 System and Its Application to Arsenic Immobilization Using Glass Formation” by Jun-Hyung Lee et al. present thermodynamic modelling of a rather difficult system to study experimentally due the arsenic content. Their thermodynamic assessment utilizes the Calphad methodology to derive the Gibbs energy functions of all relevant phases from room temperature to high temperatures utilizing all available experimental data, as well as previous assessment works. The results reported contribute to the safe Au extraction processes from the typical As-containing ore minerals.

As such, the articles compiled in this issue should be of interest to a broad readership including those planning to minimize environmental footprints while promoting sustainable production of the non-ferrous metals meeting future demands. All titles and authors of the articles published under the topic “Thermodynamic Modeling of Sustainable Non-Ferrous Metals Production: Part II” in the

September 2020 issue (vol. 72, no. 9) of *JOM* are listed below. The articles included in part II can be fully accessed via the journal's page at: http://link.springer.com/journal/11837/72/9/page/1.

- "Combination of Pyrolysis and Physical Separation to Recover Copper and Tin from Waste Printed Circuit Boards" by X. Wang, F. Jiao, W. Qin, Z. Li, N. Wang, W. Liu, and C. Yang.
- "Recycling of Spent Lead-Acid Battery for Lead Extraction with Sulfur Conservation" by Y. Li, S. Yang, P. Taskinen, J. He, Y. Chen, C. Tang, and A. Jokilaakso.
- "Recovery of Lead from Spent Lead Paste by Pre-Desulfurization and Low-Temperature Reduction Smelting" by B. Xie, T. Yang, W. Liu, D. Zhang, and L. Chen.
- "Phase Equilibrium Study of the CaO-SiO_2-MgO-Al_2O_3-TiO_2 System at 1300 °C and 1400 °C in Air" by J. Shi, M. Chen, X. Wan, P. Taskinen, and A. Jokilaakso.
- "Thermodynamic Modeling of the Na_2O-SiO_2-As_2O_5 System and Its Application to Arsenic Immobilization Using Glass Formation" by J.-H. Lee, S.Y. Kown, P. Hudon, and I.-H. Jung.

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