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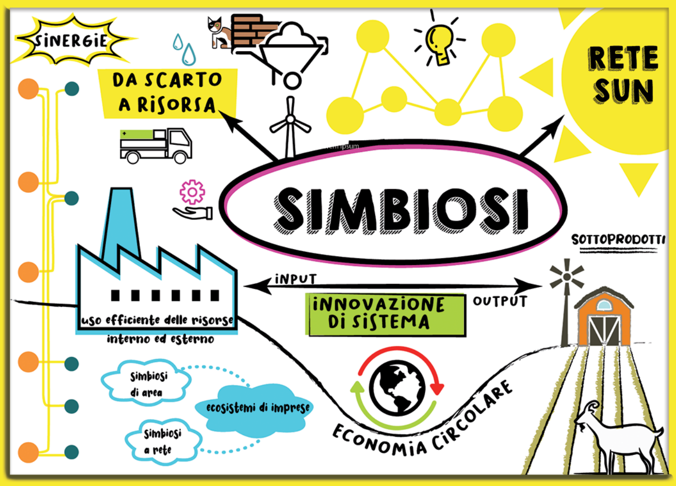

Il contributo ed il potenziale della Simbiosi Industriale per la transizione ecologica

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ANALYSIS OF THE SYNERGIES OF INDUSTRIAL SYMBIOSIS CONCERNING THE STEEL WASTE IN INDUSTRIAL AREAS

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ABSTRACT

The main by-product of the steel industry is slag whose production is functional to that of the steel itself. This work aims to analyze the cases of industrial symbiosis implemented in various countries with particular attention to the exchange of slag which, from steel mill waste, becomes a secondary raw material for other industrial sectors. In all, 12 cases of scientific literature relating to industrial areas were analyzed, and classified in function of the type of slag (deriving from different production processes). The final application of the slags is studied in terms of receiving sector and the barriers to the implementation of industrial symbiosis. It was found that the cement and road constructions industries are the main symbiotic receiving partners. In the scientific literature the reuse of slag is extensively studied in cases of integrated cycle steel production, while the case studies involving electric furnace slag are much more limited.

Keywords: *BF-BOF slag, EAF slag, industrial symbiosis, steelmaking, waste reuse*

Introduction

The attention of manufacturing industries in recent years has increasingly focused on the implementation of systems aimed at improving the recycling rate of by-products and the valorization of waste as an environmentally and economically advantageous alternative to the ever-increasing disposal costs. This is due to the increasing sensitivity towards the preservation of natural resources and the big problem of waste disposal that led the EU commission to issue Directive 2008/98 [1] and the ambitious goal of "zero waste". The production of cast iron and steel derives from two main paths: production based on iron ore (integrated process by the blast furnace-basic oxygen furnace (BF-BOF) route) and production of based on ferrous scrap (by the electric arc furnace (EAF) route). More than 70% of the world's steel is produced using the integral cycle, based on the blast furnace (BF), where iron ore is reduced to cast iron, which is subsequently converted to steel in the basic oxygen furnace (BOF). The remaining 30% follows the second route, where the ferrous scrap is melted by the electric arc furnace (EAF) and refined in ladle furnace (LD). For this reason, the emphasis is mainly placed on case studies involving integrated steel mills. Slag is the by-product produced in greater quantity. The slag is functional to the production of the metal itself as it has the task of removing the impurities present in the iron ore, steel scrap and other added components, protecting the liquid metal from oxygen and maintaining the temperature inside the furnace. With a view to circular economy, it should be emphasized that the enhancement of by-products does not aim only at their use in the production of conventional products but also at the study and development of new products. Through a new destination of secondary materials, on the one hand, large quantities will be saved from landfills and, on the other, savings will be made in the extraction of new raw materials.

Methods

It was from the literature by selecting several key words such as "industrial symbiosis in the steel sector", "slag reuse", "steel sector by-product reuse", "steel sector waste reuse" and "circular economy in the steel sector". The search engines used included databases such as Web of Science and Scopus, and freely accessible search engines, such as ResearchGate and Google Scholar.

Due to the small number of cases of industrial symbiosis involving electric arc furnace slag, a more targeted research was carried out in this regard. Therefore, two real cases of the enhancement of EAF slag in Italy have been added: Alfa Acciai (Brescia, Italy) and Global Blue (ABS) (Udine, Italy). They are not reported in the scientific literature and are not classifiable as cases of industrial symbiosis, nevertheless the authors considers them not negligible in relation to the purpose of this study.

Results

1. **Taranto, Italy** [2]

Steel production process: Integrated cycle; Industrial symbiosis model: Bottom-Up
Industrial symbiosis description: Within a complex network of symbiosis, BF slag and mill scale are sold as a substitute raw material to the cement plant.
Barriers: Long-term economic return. Lack of information and communication (need for a mediator). Corporate core business focused exclusively on the product. Poor trust in partners. Unclear legislation.
Benefits: Reduction of waste in landfills. Less exploitation of natural resources.

2. **Styria, Austria** [3, 4]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down
Industrial symbiosis description: BF sand and slag are sold to the cement and construction industry.
Barriers: Poor trust in partners. Slow bureaucracy.
Benefits: Reuse of 200,000 tons of Steel mill slag, 85,000 tons of blast furnace slag.

3. **Kwinana, Australia** [3, 5, 6]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: Within a complex network of symbiosis, BF slag is sold to the cement industry.

Barriers: Availability of (reliable) recovery/recycling technologies. Relatively low price for utility resources. Confidentiality regarding commercial matters. Intensive approval procedure for the reuse of by-products. Logistic distance between companies. Core business focus on the product.

Benefits: Avoided 260,000 tons of materials from being landfilled annually.

4. **Jinan, Cina** [7]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: Within a complex network of symbiosis, the BF slag is sold to the cement and road construction industries.

Barriers: Not described.

Benefits: Revenues from sales to the cement industry 10 M USD/year. Avoided cost of disposal 5 M USD/year. Avoided slag landfilling 180 Mt/year.

5. **Liuzhou, Cina** [8, 9]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: BF slag and steel mill dust are reused in the cement and construction industry. The by-products of the desulphurization process are used to produce fertilizers.

Barriers: Absence of specific waste treatment sites.

Benefits: Saving of about 2.4 M tons of raw materials. Reduction of about 3.4 M tons of solid waste.

6. **Lin-Hai, Taiwan** [10, 11]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: BF and BOF slag is used in the cement and construction industry, while desulfurization slag is also sold as fertilizer.

Barriers: Laws governing intellectual property rights often make it difficult to share information between industries. Slow burocracy, Unclear legislations.

Benefits: Reduction of energy costs and waste disposal.

7. **Kawasaki, Giappone** [11, 12]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: The use of BF slag as a substitute for clinker for the production of cement accounts for 56% of the material exchanges.

Barriers: Wet granulation of slag requires large amounts of water. Lack of a standardized system for waste management.

Benefits: 565 000 tonnes of waste avoided from incineration and landfill (whole symbiosis network).

8. **Puhang, Corea del sud** [13, 14]

Steel production process: Integrated cycle; Industrial symbiosis model: Top-down

Industrial symbiosis description: The BF slag is supplied to an adjacent cement plant as a substitute for clinker. The non-ferrous fraction of the recycled steel slag is used in cement (fine particles) and construction (coarse particles).

Barriers: Low demand for recycled products. Lack of standards dedicated to recycled products.

Benefits: -40% atmospheric emissions and 98.3% recycling of by-products (whole symbiosis network).

9. **Texas, USA** [15]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: EAF slag is used in the cement plant adiacent to the still mill.

Barriers: Not described

Benefits: Reuse of 130,000 tons of steel slag.

10. **Avesta Svezia** [11, 16]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill sells 77% of the slag to an infrastructure company that markets it as recycled aggregate.

Barriers: Not described

Benefits: Cost of secondary raw materials compared to traditional aggregates. Cost of disposal avoided.

11. **Unknown, Brasile** [17]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill donates the slag to an outsourced company that sells it to secondary markets after treatment, mainly for the conservation of local roads.

Barriers: Transportation costs. Lack of research.

Benefits: Avoid landfill of 144,000 tons/year of waste.

12. **Ferriere Nord, Udine, Italia** [18]

Steel production process: Electric; Industrial symbiosis model: Top-down

Industrial symbiosis description: The steel mill sends the EAF slag to treatment plants for reuse in the asphalt. The LF slag is treated to be used as a substitute for lime and reintroduced into the cycle.

Barriers: Not described.

Benefits: Reuse of EAF slag 200ktons/year as Basalt and porphyry replacement. Reuse of 30ktons/year LF slag and refractories as Lime replacement.

13. Alfa Acciai, Brescia, Italia [19]

The slag produced during the melting of the scrap in the electric furnace constitutes the raw material of the ALFA-Sinstone® granulate, usable for civil engineering works and road construction. This material is a valid substitute for the non-renewable natural raw material.

14. Global Blue (ABS), Udine, Italia [20]

The slag produced in the steel mill ABS constitutes Ecogravel® products that are mainly used for the construction of roads. Ecogravel contributes to the reduction of waste to be sent to landfills and CO_2 emissions and allows less exploitation of natural resources.

Discussion and Conclusion

In this work, 12 cases of industrial symbiosis in the steel industry in Asia, America, Australia and Europe are analysed. Most of the cases analysed consist in the production of integral cycle steel. In order to investigate the reuse of EAF waste, especially in the Italian territory, two cases (indicated as +2) were analysed that do not consist of real cases of symbiosis. The cases of Brescia and Udine provide for the treatment of EAF and LF slag for the production of aggregates with their own CE marking which bring economic and environmental advantages but which are nevertheless more a valorisation of the waste transformed into a finished product to be marketed (Ecogravel and Alfa Sinstone) than a symbiotic activity. Also in the case of Avesta and Osoppo the slag is transformed into finished products (OKTO-products and Granella respectively) but in these cases the marketing is carried out by an infrastructure companies which, by combining traditional products, offers a sustainable alternative. In addition, other symbiotic exchanges were also highlighted. While all industrial symbiosis activities at Asian sites (except Lin-Hai) have been induced by government initiatives via China's Five-Year Development Plan, Japan's Eco-Town Program, or South Korean EIP Initiative, the symbiotic connections documented in the rest of the world (EU, USA, AUS) have spontaneously formed from the motivation of cost reduction. In most of the industrial symbiosis activities defined in the analysed case studies, the cement and building materials industry is involved as a receiving symbiotic partner. The most frequent synergistic exchange is the use of BF slag and steel slag as a substitute for clinker for the production of cement.

References

1. European Commission (2008) DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE

COUNCIL. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF
2. Notarnicola B, Tassielli G, Renzulli PA (2016) Industrial symbiosis in the Taranto industrial district: Current level, constraints and potential new synergies. J Clean Prod 122:133–143. https://doi.org/10.1016/j.jclepro.2016.02.056
3. Schwarz EJ, Steininger KW (1997) Implementing nature's lesson: The industrial recycling network enhancing regional development. J Clean Prod. https://doi.org/10.1016/s0959-6526(97)00009-7
4. Onita JA (2006) How dowa industrial symbiosis influence environmental performance? 61
5. Van Berkel R, Fujita T, Hashimoto S, Fujii M (2009) Quantitative assessment of urban and industrial symbiosis in Kawasaki, Japan. Environ Sci Technol. https://doi.org/10.1021/es803319r
6. Van Beers, D., A. Bossilkov, and R. van Berkel A (2005) Status report on regional synergies in the Kwinana Industrial Area. Perth, WA, Australia
7. Geng Y, Liu Z, Xue B, et al (2014) Emergy-based assessment on industrial symbiosis: a case of Shenyang Economic and Technological Development Zone. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-014-3287-8
8. Dong L, Gu F, Fujita T, et al (2014) Uncovering opportunity of low-carbon city promotion with industrial system innovation: Case study on industrial symbiosis projects in China. Energy Policy. https://doi.org/10.1016/j.enpol.2013.10.019
9. Sun L, Li H, Dong L, et al (2017) Eco-benefits assessment on urban industrial symbiosis based on material flows analysis and emergy evaluation approach: A case of Liuzhou city, China. Resour Conserv Recycl. https://doi.org/10.1016/j.resconrec.2016.06.007
10. Song Q, Li J, Zeng X (2015) Minimizing the increasing solid waste through zero waste strategy. J Clean Prod. https://doi.org/10.1016/j.jclepro.2014.08.027
11. Krese G, Dodig V, Lagler B, et al (2018) Global trends in implententing the industrial symbiosis concept in the steel sector. In: International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM. pp 485–496
12. Ohnishi S, Dong H, Geng Y, et al (2017) A comprehensive evaluation on industrial & urban symbiosis by combining MFA, carbon footprint and emergy methods—Case of Kawasaki, Japan. Ecol Indic. https://doi.org/10.1016/j.ecolind.2016.10.016
13. Park J-H, Jung I-G, Seo J-G, Kim S-H (2015) Current Status of By-products Generation and Industrial Symbiosis Network in Pohang, South Korea. J Korea Org Resour Recycl Assoc. https://doi.org/10.17137/korrae.2015.23.1.063
14. POSCO (2019) POSCO CORPORATE CITIZENSHIP REPORT 2019 ECONOMIC, ENVIRONMENTAL, SOCIAL & GOVERNANCE PERFORMANCE
15. Mangan A, Olivetti E (2010) By-Product Synergy Networks: Driving Innovation through Waste Reduction and Carbon Mitigation. In: Sustainable Development in the Process Industries: Cases and Impact
16. Morrison S, Morrison S, Fiction E, Coover R (2018) Destia annual report 2017
17. Sellitto MA, Murakami FK (2020) Destination of the waste generated by a steelmaking plant: a case study in Latin America. Aestimum 77:127–144. https://doi.org/10.13128/aestim-9025
18. Bianco L, Porisiensi S, Baracchini G, et al (2018) Circular Economy in EAF Process: How to Make It Sustainable with Zero Waste Project in Ferriere Nord. Univers J Manag 6:190–197. https://doi.org/10.13189/ujm.2018.060602
19. Comune di Brescia Settore ambiente ed Ecologia (2021) Rapporto dell' Osservatorio Alfa Acciai 2021.

Brescia
20. Expometals.net (2020) A closer look at ABS departments: Global Blue. In: expometals.net. https://www.expometals.net/en-gb/news-page-abs-acciaierie-bertoli-safau/a-closer-look-at-abs-departments-global-blue-id23917. Accessed 27 Sep 2021