Hydrogen Exploitation on Extractive Industry Oriented to Green Electrification and Heat Production

Antonis Peppas[1], Chrysa Politi[2], Sotirios Kottaridis[3], Lampros Karalis[4], Panagiotis Angelopoulos[5] and Maria Taxiarchou[6]
1. Assistant Professor
2. Junior Researcher
3. Junior Researcher
4. Senior Researcher
5. Senior Researcher
6. Associate Professor
School of Mining and Metallurgical Engineering, National Technical University of Athens (NTUA), Athens, Greece
Corresponding author: peppas@metal.ntua.gr

Abstract

With an annual global CO_2 emission of 34 billion tonnes due to fossil fuel usage, the need for a worldwide gradual decarbonisation plan is urgent. To meet the environmental milestones of 2050, the world needs to contribute an annual 6 % decrease in fossil fuel use, accounting for 73 % of global CO_2 emissions. For achieving these goals, Energy Intensive Industries should examine establishing alternative energy supply routes and circular system processes to minimise the need for fossil fuel external energy sources, wastes etc. Hydrogen is widely used in Extractive Industries as a reduction agent for numerous metal oxides, such as iron or cobalt, producing metal with improved environmental footprint. In the aluminium industry, the H_2 reduction is not applicable till now, mainly due to the need for very high temperatures and energy demands required for the reduction process. However, H_2 shows great potential as a very efficient and environmentally beneficial fuel for heat and electricity cogeneration, which can also be easily produced inside the aluminium production and process line. Additionally, the innovation potential for exploiting H_2 for the reduction of primary aluminium production wastes, such as bauxite residues enables their valorisation of wastes transforming them into high added value materials. This paper aims on reporting state-of-the-art H_2-based technologies for green electrification and medium / high-grade heat production and proposes a utilisation scheme for secondary aluminium smelting, presenting also the environmental advantages in comparison with conventional fossil fuel-based technologies. The proposed scheme enables a reduction of 49 %, 81 % and 61 % in global warming potential, acidification potential and photochemical oxidant formation respectively.

Keywords: Extractive industry decarbonisation, Green electrification, Medium / high grade heat production, Hydrogen, Aluminium.

1. Introduction

During the last decades, the world has taken a turn towards climate-neutral practices for the facilitation of environmental goals. To limit the global temperature rise by 1.5 ˚C, in line with the Paris Agreement, the world must contribute to a roughly 6 % annual reduction of fossil fuels, including coal, oil and gas. All coal-fired power stations will cease operations by 2040 at the latest [1]. With such industries making up more than half of the energy consumption in the EU, Energy Intensive Industries (EIIs) are responsible for 15 % of the EU's emissions [2]. These emissions are expected to significantly increase as the demand and needs of major EIIs (i.e., Extractive industries), see a constant rise.

In 2017, extraction of materials reached 92 billion tonnes in comparison with the 27 billion in 1970. If this trend continues, the annual global demand will reach 190 billion tonnes of material by 2060 [1]. More specifically, with the expected population and economic growth over the coming decades, global steel demand is expected to increase by approximately 30 %, while the demand for cement will be increased by 10 % and aluminium (Al) by about 75 % until 2060 compared to 2017 levels [3]. Despite the severe effects of Covid-19 on global markets, primary Al production in 2020 increased by 2.3 % to 65.3 million tonnes, and global Al demand was 98 million tonnes with recycling [4].

This rise in global demand consequently exacerbates the environmental challenge. The extraction and primary processing of metals and minerals accounted for 26 % of the Global Greenhouse Gas (GHG) emissions and 20 % of health impacts in 2019 [5, 6]. In 2021, the metals and mining sector was estimated to emit around 4.5 Gt of CO_2 equivalent per year [7]. Al in particular appears to be the most EII and the most CO_2-emissive. The high emissions are the result of fossil fuel usage. For that matter, an extensive investigation of the potential reduction of GHG emissions through fossil fuel use reduction is taking place, concerning the electrification of energy-intensive processes. Electrification is particularly challenging for fossil resources not used as energy supply but as feedstock. Replacing fossil fuels with electricity is not always directly possible since fossil fuels serve two use cases in EIIs: 1) supply of process heat by combustion and 2) use as a chemical feedstock. As such process heat demands are typically large, there is a limited number of alternatives to fossil fuels that can provide the required consistency, high temperatures and fluxes, thus making the minimization of fossil fuel need even more important.

Europe has historically a strong presence in metallurgy, representing about 7 % of the global production, around half of which comes from within the EU28, deploying more than 15 smelters, of which two were idled in 2019, and 600 Al production plants ranging from raw materials (e.g., bauxite and alumina), primary metal production, semi-fabrication (e.g rolling and extrusion), and recycling. In this regard, melting and heat treatment furnaces are widely used in the Al industry [8]. These furnaces have burners that are used with fossil fuels. Therefore, developing retrofitting solutions for existing infrastructure is a key enabler for the implementation of the H_2 technologies. With relatively small modifications to existing combustors, co-firing of H_2 can be allowed to significant fractions (>30 % vol., 11 % of C reduction) [9]. Overall, over half of our Europe's Al smelters have been affected by the power crises in the course of 2022. according to Eurométaux, the EU has temporarily lost 650 000 tonnes of primary Al capacity: about 30 % of its total. [10] Due to all these needs, the investigation of clean energy technologies is vital to ensure the adaptation of sustainable and responsible practices from the extractive industries as to meet the rising mineral demands up to 2050.

The main challenges are faced from secondary Al production which is a process of recycling Al scrap into ingots. Al recycling not only reduces the wastes that would otherwise be disposed, but also minimises the need for processes, such as alumina reduction for the primary Al production, making the production 95 % more energy efficient [11]. During secondary Al smelting, the scrap is extracted from wastes and then fed to the smelter to be melt at temperatures higher than 700 °C [11]. The main component of a secondary Al smelter is the furnace, in which the Al scrap is placed to be heated beyond its melting point by high-grade heat provided by fuels combustion through burners. In some cases, the required heat is provided by electricity or other energy sources. In addition, pre-heating of the material is required in order to remove moisture, prevent explosions in the furnace and reduce melting energy requirements [12]. After the smelting process, molten Al is transported to holding furnaces in the cast house to be turned into ingots [12].

In this study, the methodology of LCA is applied in order to evaluate the environmental impact associated with the energy and material flows within a secondary Al smelting plant and validate the green nature of the H_2-based CHP technologies in comparison to the conventional CHP production. The results show the transition towards H_2 technologies to be highly beneficial in terms of both efficiency and emissions reduction. Incorporating ICE and SOFC systems for H_2-based high grade heat production substantially decreased the energy demand from outside sources. Additionally, the proposed scheme appeared to have almost 49 % less impact than the current practises in terms of GWP, 81 % in terms of AP and 61 % in terms of POF.

This proposed scheme can serve as a basis for further investigation on secondary self-sustained H_2-fuelled systems, supporting the main metallurgical processes. Further studies are recommended to address factors including the detailed techno-economic analysis of energy systems with integrated green H_2 production, which can provide to the EIIs an additional role as decentralised green power stations.

6. References

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