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SELECTED ASPECTS OF DECARBONIZATION OF PRODUCTION SYSTEMS IN THE METALLURGICAL INDUSTRY

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This paper discusses the growing importance of decarbonising production systems in the metallurgical industry as a response to climate challenges and increasing sustainability requirements. Many solutions are currently being implemented and tested in the metallurgical industry, but the problem of meeting the carbon emissions target remains complex and difficult. The metallurgical industry is one of the branches of industry that generates significant amounts of carbon dioxide emissions due to the energy consumption during the metal melting and forming process. The paper presents several possible decarbonisation strategies available to smelters, such as the use of renewable energy, the utilisation of more efficient melting technologies, or the implementation of low-energy technologies throughout the production process. Application examples from different countries illustrate how these strategies are already being applied in practice, as well as potential obstacles and challenges on the road to full decarbonisation.

Keywords: decarbonization, renewable energy, metallurgical production

INTRODUCTION

Decarbonisation of the metallurgical industry refers to measures aimed at reducing emissions of greenhouse gases, particularly carbon dioxide. The reduction of CO_2 emissions is increasingly being considered as a key element in the strategies of metallurgical plants worldwide. Greenhouse gas (GHG) emissions from fossil fuels, not only in Europe but also worldwide, are currently among the most important concerns, and reducing the industry's carbon footprint has become an overarching objective of the European Union [1]. The metallurgical, iron and steel sector has already made a number of improvements over recent years that have led to reduced energy consumption, improved energy efficiency, reduced pollutant emissions and increased scrap recycling rates, among other things. However, these measures are still not sufficient. Metallurgy is one of the branches of industry that generates significant amounts of carbon dioxide emissions as a result of the high energy consumption in the process of melting and forming metals. Another equally important reason for decarbonisation is regulatory requirements. Many countries and regions are introducing stringent regulations to reduce greenhouse gas emissions. Another element of the decarbonisation process is the growing sustainability pressure on companies competing in the economic market. The implementation of more efficient and environmentally friendly technologies in metallurgical processes, the modernisation of equipment, and the change of energy sources leads to a reduction in energy and material consumption. Furthermore, the decarbonisation process can stimulate technological innovation in the industry. Analysing legal developments and guidelines of all kinds, it can be concluded that the decarbonisation process in the metallurgical industry is a challenge, but also a necessity in order to reduce the sector's impact on climate change, which will ultimately contribute to achieving the sustainable development goals.

EUROPEAN UNION REGULATIONS AND GUIDELINES FOR THE DECARBONISATION OF PRODUCTION SYSTEMS

The laws and regulations forcing actions aimed at decarbonising production systems, and changing the economy as a whole, are largely based on European Union guidelines. The EU has introduced a number of policies, regulations, and initiatives. The most important of these include [2]:

European Union Climate Package – Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing a framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999. This package consists of a number of legal acts that aim to reduce greenhouse gas emissions and accelerate the transformation of the industrial sector towards more sustainable production.

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Greenhouse Gas Emissions Trading System (EU ETS) Directive – Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the European Union is the EU's primary instrument to reduce greenhouse gas emissions in the industrial sector.

The Energy Efficiency Directive (EED) – Directive 2012/27/EU on energy efficiency and Amending Directive (EU) 2018/2002 on energy efficiency is one of the European Union's key initiatives to improve energy efficiency in Europe [3]. The Directive aims to promote energy savings, reduce energy consumption and limit greenhouse gas emissions associated with energy production and consumption.

METALLURGICAL INDUSTRY

Metallurgical processes include a number of industries involved in the extraction, processing, and treatment of metals. Among the most significant in terms of carbon dioxide emissions for the metallurgical industry are: ferrous and steel metallurgy, non-ferrous metallurgy and the casting industry. These metallurgical industries form components of the system for converting mineral raw materials into finished metal products that are used in various sectors of the economy.

In 2023, global production of crude steel was around 1.85 billion tonnes. The largest steel producers are China, which produced 1019 million tonnes of steel in 2023, accounting for 54% of global production. India is second with a production of 140.2 million tonnes in the same period. In the European Union, crude steel production in 2023 was around 126.3 million tonnes, which is a decrease of 10% compared to the previous year. In January 2024, EU steel production was 10.2 million tonnes, a decrease of 1.8% compared to January 2023. Steel demand is expected to increase by 5.3% in 2025, following a technical rebound in 2024.

Global casting production is reaching significant levels in terms of both volume and market value. In 2020, the global production of castings was 105.5 million tonnes, despite a 6.4% decline since 2018. China is the world's largest producer of castings, producing 49.4 million tonnes in 2023, while India comes second with a production of 12.1 million tonnes. [5,6].

This result would have been considerably worse had it not been for the production of the Chinese casting industry – with 51.95 million tonnes of castings produced, which actually represented a 6% increase in production. Among other countries, the casting industry suffered the biggest losses in Japan (-34.7%) and Germany (-29.6%). In India, the decrease in castings production during the pandemic crisis was, in fact, relatively small (-1.5%), while in the US, the industry's production decreased by as much as 13.7%. As a result, 11.31 million tonnes of castings were produced in India and only 9.75 million tonnes in the US.

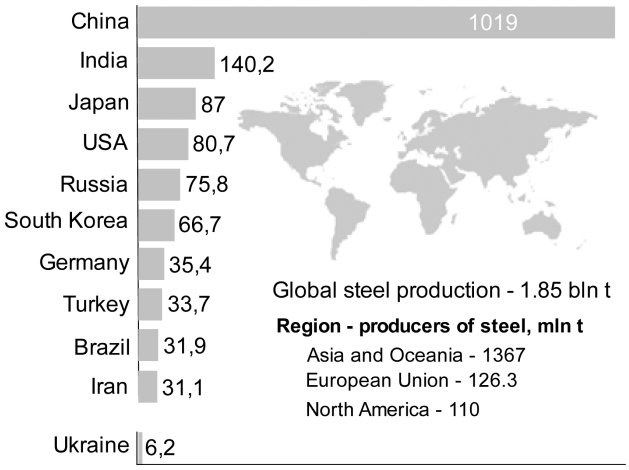

Figure 1 Steel production 2023 [4]

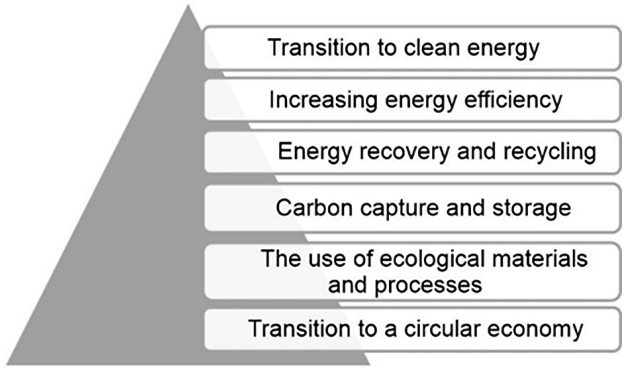

Figure 2 Possible decarbonisation strategies [7, 8].

DECARBONISATION – STRATEGIES AND APPROACHES TO THE PROCESS

Taking into account the specifics of the production process, a number of measures, decarbonisation strategies, can be distinguished (Fig. 2).

Clean energy transition: one of the most important parts of decarbonisation is the replacement of fossil fuels (coal, oil, natural gas) with energy from renewable sources such as solar, wind, or water energy [9, 10].

Improving energy efficiency: involves improving the energy efficiency of machinery and processes, enabling the same quantities of goods to be produced with less energy consumption and lower CO_2 emissions.

Energy recovery and recycling: in many production systems, it is possible to reduce CO_2 emissions by using «waste heat» for heating or for energy generation [11].

Carbon Capture and Storage (CCS): the technology involves capturing CO_2 from industrial emissions and storing it underground, rather than allowing it to be emitted into the atmosphere.

Use of eco-friendly materials and processes: this includes using materials with a lower carbon content and investing in innovative manufacturing processes that emit less CO_2.

Shift to a circular economy: this approach is about maximising the use of resources, through their long-term use, repair, reuse and recycling, rather than the traditional «produce, use, discard» model.

DECARBONISATION IN METALLURGICAL PROCESSES

The choice of an appropriate decarbonisation strategy by a country, region, or company depends on a number of factors that can include economic, technological, political and social aspects. Among the key aspects to consider when choosing a decarbonisation strategy are:

- Natural resource availability. A country or region rich in natural resources such as sun, wind, water, or biomass may lean towards decarbonisation strategies based on renewable energy.
- Economic structure and energy resources. Regions reliant on fossil fuels, such as coal or gas, may require a more gradual transition with the application of Carbon Capture and Storage technologies.
- Innovation and technology. The availability of advanced technologies, such as energy storage, advanced insulation materials or smart grids, may accelerate the decarbonisation process.
- Policies and regulations are highly conducive. Government support: Subsidies, tax credits and other forms of government support can promote specific technologies or practices.
- Socio-economic factors. Implementing change requires the support of society; education and community involvement are key to the success of a decarbonisation strategy.
- Infrastructure, state of existing infrastructure. Adaptation or replacement of existing energy infrastructure may be necessary and influences the decarbonisation strategy.

In summary, the choice of an appropriate decarbonisation strategy will depend on a comprehensive analysis of many factors and the ability to balance them to achieve sustainable development, reduce greenhouse gas emissions and safeguard long-term social and economic interests.

KEY AREAS FOR DECARBONISATION OF METALLURGICAL PROCESSES WORLDWIDE

Decarbonisation, the reduction of carbon emissions, is increasingly being considered as an important part of the strategy of metallurgical companies around the world. Key areas related to the decarbonisation of metallurgical processes include:

- Sustainable development and energy saving in metallurgical plant production systems – measures for sustainable production include increasing energy efficiency, reducing waste and pollution, and using renewable energy sources.
- Digitisation and automation of processes – like many other sectors, the metallurgical industry is also increasingly using digital technology and automation to improve production processes.

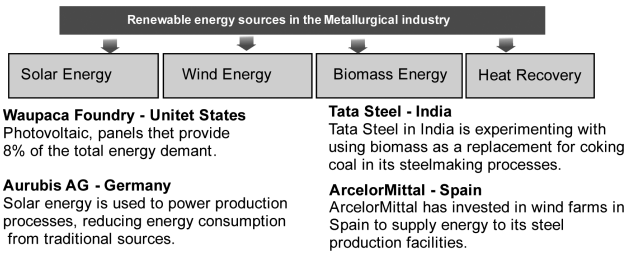

Figure 3 Selected examples of the application of renewable energy sources in the metallurgical industry [12, 13].

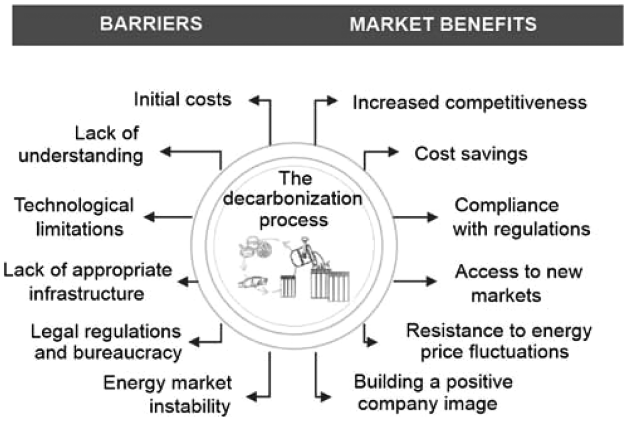

Figure 4 Market barriers and benefits of the decarbonisation process of the metallurgical industry

- Innovation in materials and processes – the casting industry is constantly looking for new materials and techniques that can improve the quality and performance of castings.
- Development of techniques related to Industry 4.0 – the use of advanced technologies, such as 3D printing, the Internet of Things, artificial intelligence, can contribute to increasing the efficiency and quality of metallurgical processes.

The decarbonisation process is associated not only with barriers (Fig. 4), but also with benefits, which include improved energy efficiency, innovation, and increased competitiveness.

SUMMARY

The metallurgical industry plays an important role in the global economy, but at the same time emits significant amounts of greenhouse gases. Decarbonisation of the sector is therefore essential to achieve global climate goals.

The choice of an appropriate decarbonisation strategy for a specific metallurgical production company will depend on a comprehensive analysis of many factors and the ability to balance them, with the aim of achieving sustainable development, reducing greenhouse gas emissions, and safeguarding long-term social and economic interests.

At the moment, direct reduction with hydrogen appears to be one of the most promising processes to achieve such CO_2 reduction in a short time. However,

the availability of large quantities of green hydrogen is one of the prerequisites for achieving the above goal. Another key aspect is the large increase in electricity demand, which must be met by renewable energy, a challenge for all stakeholders involved.

Finally, it is likely that no single option or technology will be the best or only solution, rather a combination of breakthrough technologies should be developed and implemented to address the problem of growing energy consumption and CO_2 emissions in the metallurgical industry.

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Note: The responsible translator for Groy Translations Sp. z.o.o., Katowice, Poland.