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Decarbonization of Production Systems in Foundries

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Abstract

The article discusses the growing importance of decarbonization of production systems in the foundry industry as a response to climate challenges and increasing requirements for sustainable development. The process of reducing greenhouse gas emissions in foundry production is caused by a number of reasons. Decarbonization of the foundry industry refers to actions aimed at reducing greenhouse gas emissions, especially carbon dioxide (CO_2). Reducing carbon dioxide emissions is increasingly being considered as a key element of the strategy of both small and large foundries around the world. Foundry is one of the industries that generates significant amounts of carbon dioxide emissions due to the energy consumption in the process of melting and forming metals. There is virtually no manufacturing industry that does not use elements cast from iron, steel or non-ferrous metals, ranging from elements made of aluminum to zinc. The article presents various decarbonization strategies available to foundries, such as: the use of renewable energy, the use of more efficient melting technologies, or the implementation of low-energy technologies throughout the production process. Application examples from different parts of the world illustrate how these strategies are already being put into practice, as well as the potential obstacles and challenges to full decarbonization.

Keywords: Decarbonization, Renewable energy, Foundry production

1. Introduction

Decarbonization of the foundry industry refers to actions aimed at reducing greenhouse gas emissions, especially carbon dioxide. Reducing CO_2 emissions is increasingly being considered as a key element of the strategies of both small and large foundries around the world. This process is caused by a number of factors. Foundry is one of the industries that generates significant amounts of carbon dioxide emissions due to the significant energy consumption in the process of melting and forming metals. Another equally important reason for decarbonization is regulatory requirements. Many countries and regions are introducing strict regulations to reduce greenhouse gas emissions [1]. The foundry industry adapts its activities to these requirements, which may include emission limits, bans on the use of certain raw materials or adjustments of production processes. Another element of the decarbonization process is the growing pressure for sustainable development of enterprises competing on the economic market. Customers, investors and society increasingly expect companies and organizations to conduct business with greater emphasis on sustainable production and ecological responsibility. The foundry industry that makes efforts to decarbonize can build a positive image and position itself as an environmentally responsible company. These considerations cannot omit the main factor of production, economics. The implementation of more effective and ecological technologies in foundry processes, modernization of equipment and change of energy sources leads to reduced energy and material consumption, which reduces production costs. Moreover, the decarbonization process can stimulate technological innovation in the foundry industry. Analyzing legal changes and EU guidelines that also apply to heavy industry, it should be stated that the decarbonization process in the foundry industry is a challenge, but at the same time a necessity aimed at reducing the impact of this sector on climate change, which will ultimately contribute to achieving the sustainable development goals. In addition to investments in technology, changes in production processes, it also requires close cooperation between government, industry and the community.

2. European Union regulations and guidelines on the decarbonization of production systems

Laws and regulations resulting in a number of actions aimed at decarbonizing production systems, as well as changes in the economy as a whole, are largely based on European Union guidelines. To achieve this, the EU has introduced a number of policies, regulations and initiatives. Poland, as a European Union member state, is obliged to comply with both national and EU regulations regarding the decarbonization of production systems. EU rules take precedence and provide the framework within which each Member State must operate, but they have a certain degree of freedom in how they implement these rules within their legal order. The most important ones include: the European Union Climate Package, the Directive on the greenhouse gas emission allowance trading system and the Energy Efficiency Directive [3,4].

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 (European Climate Law) is a central element of regulations for decarbonizing production systems. The package consists of 12 proposals for legislative changes on climate and energy that are intended to enable transit. The new climate target and package are key elements of the European Green Deal. This package consists of a number of legal acts aimed at reducing greenhouse gas emissions and accelerating the transformation of the industrial sector towards more sustainable production.

Greenhouse Gas Emissions Trading Scheme (EU ETS) Directive - 2003/87/EC establishing a greenhouse gas emission allowance trading system in the European Union is the main EU instrument aimed at reducing greenhouse gas emissions in the industrial sector. Under the EU ETS, companies must have an appropriate number of emission allowances that are traded on the market. The current, fourth stage of the EU ETS system covers the years 2021–2030. The European Union has set a new, higher target for this period, which is to reduce greenhouse gas emissions by 62% compared to 2005 levels.

The system applies to:

- power plants;
- many different energy-intensive industries;
- sea transport;
- gas emissions.

This system imposes limits on emissions and charges companies that exceed those limits. This is an important economic stimulus that encourages investment in low-emission technologies and reduces greenhouse gas emissions in the production sector.

Energy Efficiency Directive (EED) - 2012/27/EU on energy efficiency and Directive (EU) 2018/2002 amending Directive 2012/27/EU on energy efficiency is one of the key initiatives of the European Union aimed at improving energy efficiency in Europe [2]. This directive was adopted by the European Parliament and the European Council and aims to promote energy saving, reduce energy consumption and reduce greenhouse gas emissions related to the production and consumption of energy.

The European Union has committed to achieving many important climate goals. One of them is to reduce greenhouse gas emissions by at least 55% by 2030 compared to pre-1990 levels. In addition, the EU aims to achieve climate neutrality by 2050, which means that net greenhouse gas emissions will be offset by the absorption of these gases by natural resources or technologies that remove carbon dioxide. On July 25, 2023, the EU officially concluded negotiations on changes to the legal framework for energy efficiency. Therefore, in August 2023, a new version of the Directive entered into force after publication in the Official Journal of the EU.

3. Foundry industry

The foundry industry is one of the industries that generates significant amounts of carbon dioxide emissions due to the energy consumption in the process of melting and forming metals.

Foundry production, as well as most industries, has had to face the crisis in recent years resulting from the outbreak of the COVID-19 pandemic in 2019, as well as the war in Ukraine. The negative effects of this crisis can be observed in the production of the foundry sector in virtually all countries except China. A number of factors related to the above-mentioned global situation, such as problems with the supply of raw materials, energy problems, problems with human resources and work organization, have led to reduced production in many sectors of the economy using foundry products. As shown in the table below (Fig. 1), in 2020 the global production of castings amounted to 105.5 million tones and was lower compared to the previous year by approximately 3.3%.

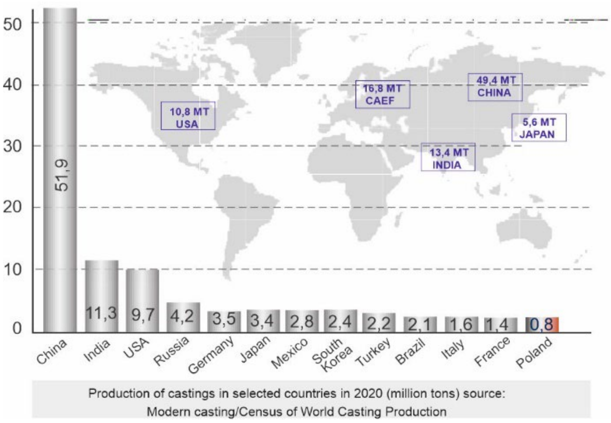

Fig. 1. Production of castings in selected countries in 2020 [6]

This result would be much worse if it were not for the production of the Chinese foundry industry - 51.95 million tons of castings produced, which was an increase in production by 6%.

Among other countries, the foundry industry suffered the greatest losses in Japan (-34.7%) and Germany (-29.6%). In India, during the crisis caused by the pandemic, the decline in casting production was relatively small (-1.5%), while in the United States, the industry's production decreased by as much as 13.7%. As a result, 11.31 million tons of castings were produced in India, and only 9.75 million tons in the USA.

The Polish foundry market is struggling with similar problems. The decline in gross domestic product resulted in reduced investments in many sectors of the economy that were the main recipients of foundry industry products. Polish foundries recorded a 20% drop in production. The most difficult situation was experienced by foundries whose main recipient was the automotive industry. Despite the difficult situation, the foundry industry plays a key role in the global economy, constituting the basis for a number of industrial sectors.

4. Decarbonization - strategies and approaches to the process

Taking into account the specificity of the production process, a number of activities and decarbonization strategies can be distinguished, Fig. 2.

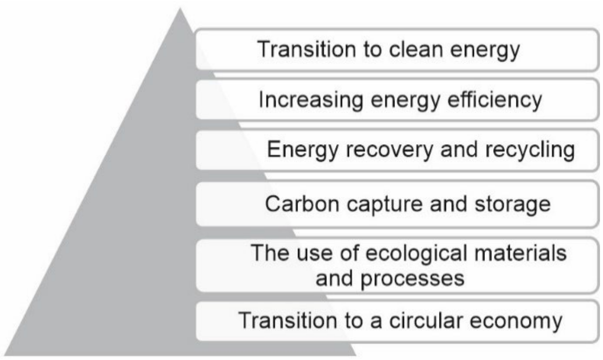

Fig. 2. Possible decarbonization strategies [7,8]

Transition to clean energy: One of the most important elements of decarbonization is replacing fossil fuels (coal, oil, natural gas) with energy from renewable sources such as solar, wind or hydropower [9,10].

Increasing energy efficiency: involves improving the energy efficiency of machines and processes, which allows the production of the same quantities of goods using less energy and CO2 emissions [11].

Energy recovery and recycling: in many production systems it is possible to reduce CO2 emissions by using "waste heat" for heating or energy production [12,13].

Carbon capture and storage (CCS): The technology captures CO2 from industrial emissions and stores it underground, rather than allowing it to be released into the atmosphere.

Use of sustainable materials and processes: This includes using materials with lower carbon content, as well as investing in innovative production processes that emit less CO2.

Moving to a circular economy: This approach is about making the most of resources, through long-term use, repair, reuse and recycling, rather than the traditional "make, use, dispose" model.

5. Decarbonization in the foundry process

Castings occupy one of the most important positions in sustainable and climate-neutral production. There is virtually no manufacturing industry that does not use cast elements made of iron, steel or non-ferrous metals, from aluminium to zinc. For some sectors, such as the production of cars or machine tools, the foundry industry is a key element of their production process. Foundry enterprises differ in production volumes, consumer industries and sales markets, types of materials and foundry technologies used, and many other aspects. Therefore, the decarbonisation process cannot be carried out according to one pattern, even though this industry has one common denominator for all foundries - energy consumption. Figure 3 shows examples of decarbonisation activities in European foundries.

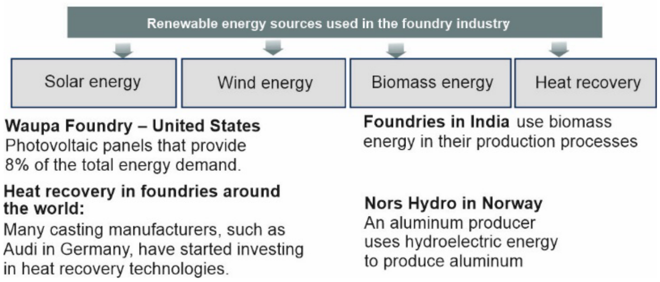

Fig. 3. Selected examples of the use of renewable energy sources in the foundry industry [14, 15]

In order to decarbonize its processes, the American foundry industry also focused its activities on recycling [16]:

- For over 10 years, Waterman Industries, a California foundry, has completely eliminated all of its landfill costs. In addition, it has recycled and developed manufacturing materials and saleable by-products out of "would-be-wastes."
- Kohler Co. of Wisconsin used 25,000 tons of foundry sand in the last three years as construction fill material in several road and building construction projects, displacing the need for virgin materials.
- Ford Motor Company's Cleveland Casting Plant beneficially reuses 100% of their spent sand in a wide variety of environmentally responsible projects. Since 1994, they have recycled over 1,000,000 tons of spent sand.
- A consortium of 33 foundries in southeastern Pennsylvania has established alternative uses for spent sand, resulting in over 80,000 tons being recycled.
- Foundries and legislators in Ohio, working with the state Environmental Protection Agency and Department of Transportation, have developed applications for foundry sand for low-strength concrete.

- A Buffalo, New York, foundry had accumulated an 8000-ton pile of spent sand on its property that would have cost $680,000 for disposal. The foundry partnered with a cement and fill manufacturer, and today that pile of sand is gone.
- Spent sand has been used to make concrete barriers, including barrier production, for the Cleveland Grand Prix car race.
- The Grede Foundry plant in Michigan built a state-of-the-art employee training facility, learning center and lunchroom using concrete blocks made from foundry slag.

The choice of an appropriate decarbonization strategy by a country, region or company depends on many factors, which may include economic, technological, political and social aspects. The key aspects to consider when choosing a decarbonization strategy include:

- Availability of natural resources. A country or region rich in natural resources such as solar, wind, water or biomass may lean towards decarbonization strategies based on renewable energy.
- Economic structure and energy resources. Regions dependent on fossil fuels such as coal and gas may require a more gradual transition using Carbon Capture and Storage technology
- Innovation and technologies. The availability of advanced technologies such as energy storage, advanced insulation materials and smart energy grids can accelerate the decarbonization process.
- Policies and regulations provide significant support Government support: Subsidies, tax breaks, and other forms of government support can promote particular technologies or practices.
- Socio-economic factors. Implementing changes requires society's support; education and community engagement are key to the success of decarbonization strategies.
- Infrastructure, condition of existing infrastructure. Adapting or replacing existing energy infrastructure may be necessary and impacts the decarbonization strategy.

In summary, the choice of an appropriate decarbonization 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 secure long-term social and economic interests.

Decarbonization, the reduction of carbon dioxide emissions, is increasingly being considered as an important element of the strategy of both small and large foundries around the world. The key areas related to the decarbonization of foundry processes include:

- Sustainability and energy efficiency of foundry production systems - as more companies become aware of their impact on the environment, many foundries are moving towards sustainable production. These actions include increasing energy efficiency, reducing waste and pollution, and using renewable energy sources.
- Digitization and process automation - like many other industry sectors, foundries are also increasingly using digital technologies and automation to streamline their production processes. More and more often, robots are planned to be used to perform heavy or dangerous tasks, and computer software significantly helps in designing molds and monitoring production processes.
- Innovations in materials and processes - the foundry industry is constantly looking for new materials and techniques that can improve the quality and performance of castings. Work is being developed on new metal alloys that are stronger, lighter or have better properties, as well as new casting techniques that can improve the quality of castings or reduce the amount of waste.
- Increasing importance of the casting sector for renewable energy - as the global renewable energy sector grows, so does the demand for castings used in these technologies. Castings are a key component for wind turbines, solar panels and other renewable energy technologies.
- Development of foundry techniques related to Industry 4.0 - the use of advanced technologies, such as 3D printing, Internet of Things (IoT), artificial intelligence, may contribute to increasing the efficiency and quality of foundry processes.

The use of innovative materials can also help reduce carbon emissions in foundry processes. These include: biodegradable molding materials, recycled materials, light metal alloys.

Tightening environmental protection requirements put pressure on the search for new pro-ecological solutions in many areas of industry, including molding sand production technology. An example of this type of action may be a change in the technology of molding sand production by introducing biodegradable, environmentally friendly additives. The assessment of the impact of biodegradable material on the parameters of the molding sand was based on tests of selected technological properties[17]. Based on the conducted research, it was found that the addition of 5% PCL to masses with hydrated sodium silicate hardened with Jeffsol/Ixional does not negatively affect their bending strength or the abrasiveness of the mass[17]. Moreover, the tests showed that the addition of 5% PCL does not negatively affect the technological properties of the tested sands. [Kompozycje: uwodniony krzemian sodu – materiał biodegradowalny, jako spoiwo mas formierskich.

Using molding materials that are biodegradable or have lower carbon emissions during production and use can significantly reduce your carbon footprint. Examples include organic resins or water-based bundles

Foundries represent an important example of circular economy, thanks to the very nature of their production process, which has always put into practice an advanced mechanism of circularity: foundries and their technology, in fact, make it possible to recycle and reuse a large part of metal materials that have reached the "end of their life" to make new products.

In recent years, the percentage of recycled materials used to replace virgin raw materials has steadily increased and now reaches 75% for foundries equipped with electric ovens [18].

Production waste is also reused in the process: 95% of the waste earth produced in the foundry is reused as raw material, replacing sand and earth from mining activities. Finally, 95% of the water used for cooling the furnaces is recovered and reused. A perfectly circular system, which makes foundries "recycle" by definition.

As regards the environmental impact of production, in 2015 the sample of companies surveyed in the first Sustainability Report of the sector allocated 28.5% of total investments to the environment.

This figure is much higher than the average for manufacturing as a whole (2%) and has made it possible to drastically reduce dust emissions into the atmosphere (-65% since 2003) and the production of waste per tonne of castings produced (-26.6% from 2000 to 2015).https://www.assofond.it/en/foundries-and-circular-economy

Another method that significantly contributes to reducing CO2 is the development of light metal alloys. The use of light metal alloys requires much less energy in the smelting process. A typical example of this is aluminum alloys, which are lighter but retain high strength.

Foundries, being key participants in the production chain in many industry sectors, face significant challenges in adapting to new, sustainable production standards fig.4. At the same time, the decarbonization process also offers a number of benefits that can bring long-term benefits for both the environment and the companies themselves.

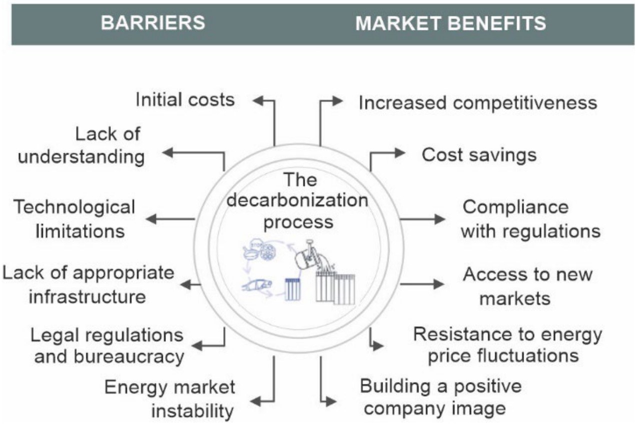

Fig. 4. Barriers and market benefits of the decarbonization process of the foundry industry

The decarbonization process is associated not only with barriers, such as high capital costs, technological limitations, political and regulatory instability, and social resistance, but also with benefits, including improved energy efficiency, innovation, and increased competitiveness.

6. Conclusions

The foundry industry plays an important role in the global economy, but at the same time it emits significant amounts of greenhouse gases. Decarbonization of this sector is therefore essential to achieving global climate goals.

The choice of an appropriate decarbonization strategy for a specific foundry production company will depend on a comprehensive analysis of many factors and the ability to balance them in order to achieve sustainable development, reduce greenhouse gas emissions and secure long-term social and economic interests.

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The key areas related to the decarbonization of foundry processes include: sustainability and energy efficiency of foundry production systems, digitization and process automation, innovations in materials and processes, increasing importance of the casting sector for renewable energy, development of foundry techniques related to Industry 4.0

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